JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF ELECTRICAL & COMPUTER ENGINEERING

GRADUATE PROGRAM IN ELECTRICAL POWER ENGINEERING

Reliability improvement of power distribution system using protection devices: case study of Bedele power distribution system

By

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Thesis submitted to Jimma University in partial fulfillment of the requirements for the degree of Master of Sciencein electrical power engineering

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MSc. Thesis

On

RELIABILITY IMPROVEMENT OF POWER DISTRIBUTION SYSTEM USING PROTECTION DEVICES: - CASE STUDY OF BEDELE POWER DISTRIBUTION SYSTEM

By

TESHOME TOLESA

APPROVAL BY BOARD OF EXAMINERS

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Declaration

I, the undersigned, declare that this MSc thesis is my original work, has not been presented for fulfillment of a degree in this or any other university, and all sources and materials used for the thesis have been acknowledged.

Teshome Tolesa__________ __________

Researcher name Signature Date

The thesis entitled, Reliability study on power distribution system case study of Bedele power distribution system submitted by Teshome Tolesa to Jimma University in partial fulfillments for the degree of master in Electrical Power Engineering is here by recommended for final evaluation and examination.

Dr. Tassew Tadewose ____________________

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Abstract

The majority of outage events experienced by customers are due to electrical distribution failures. Increasing distribution network reliability is a necessity in order to reduce interruption events. Unreliable power distribution reduces user power consumption, affects daily activity and drags modern life style. Basically, Power Distribution Reliability has been a major challenge in Bedele city. It has incurred cost on customers and lowered product quality. In Bedele city and surround, Customers have faced frequent interruption and utility has taken long time to alleviate it. Hence, it has to get amicable solution. Thus, the objective of the study is to assess the reliability of the current distribution system and suggest solutions of reliability improvement.

Bedelepower distribution system of south west region, which has high rate of interruption, is selected as case study area. Bedele city and surrounds feeder lines reliability is assessed based on two years datafrom Ethiopian electric power (EEP) of south west region. To limit the scope of the study, Bedele city and Brewery Factory line from Bedele substation is chosen for reliability improvement measures. Bedele cityFeeder has SAIDI of 710 hour per customer per year and SAIFI of 617 Interruption per customer per year. And Bedele Brewery factory has SAIDI of 320 hour per customer per year and SAIFI of 272 Interruption per customer per year. The reliability index values of both feeders are not within the ranges of bench marks of best practices and Ethiopia’s reliability requirement.

Therefore, the appropriate components of Distribution system reliability improvement protection devices are selected. Different power distribution system cases are analyzed by considering feeder segmentation and auto restoration improves distribution reliability. Each cases payback period and reliability performance of distribution system evaluated. The reliability assessment of power distribution system with protection device is simulated using the ETAP software. The simulation of the power distribution models shows that the application of reclosers can improve the reliability of the overall system from 47% to 83%. Finally, best scenario is selected and proposed as a solution to improve Distribution reliability of the two feeders for implementation.

Key words: -Reliability, power distribution system, Reclosers, Reliability indices, TCC curve, DigSilent, ETAP

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List of Abbreviations

ASAI Average Service Availability Index

ASUI Average Service Unavailability Index

CAIDI Customer Average Interruption Duration Index

CAIFI Customer Average Interruption Frequency Index

CTI Coordination time interval

Cust Customer

DPEF Distribution Permanent Earth Faults

DPSC Distribution Permanent Short Circuit

DTEF Distribution Transient Earth Faults

DTSC Distribution Transient Short Circuit

DUR Duration of Interruptions

E.C Ethiopian Calendar

EEA Ethiopia Electric Agency

EEPEthiopian Electric Power

EEU Ethiopia Electric Utility

EF Earth Fault

ENS Energy Not Supplied Index

FCI Fault Circuit Indicator

HRC High Rupturing Capacity

IEEE Institute of Electrical and Electronics Engineers

Int Interruption

Kmkilometer

KVKilo Volt

KVA Kilo Volt Ampere

OC over Current

SAIDI System Average Interruption Duration Index

SAIFI System Average Interruption Frequency Index

TCC Time Current Characteristics

CHAPTER ONE

INTRODUCTION

1.1. Background

Bedele city is located at some 456 kilometers from Addis Ababa, on the South west part of the country Oromia region, Ilu Aba bor zone.The 2007 G.C national census reported a total population for Bedele city of 19,517, of whom 9,837 were men and 9,680 were women. Since 1982, the city has been supplied from national grid. Bedele sub-district office has about 5953 customers in 2007 E.C. that supplied from Bedele city line.

A 132 kV incoming transmission line from Nekemte substation is stretched into the Bedele substation. There is also outgoing line from Bedele to Mettu which is 230KV transmission line. The distribution system Feeder in Bedele city has a primary voltage of 15 kV which is allocated based on the parameters of the Ethiopian Electric Utility (EEU). And also, this voltage value is stepped down to 380 and 220 volts to customer's level.

I have selected Bedele city for the power Distribution system reliability study because of the following main reasons. (1) The proposed problems are clearly visible in the existing power distribution system, and (2) Being one of the industry and business centers of zone, the solution of the problem will have significant impact on the economy of the area.

Since the distribution system of Bedele city has many problems, using protection along the feeder has been proposed as a solution to solve the problems. The term smart grid has been in use since at least 2005 [19]. The term had been used previously and may date as far back as 1998. There are manysmart grid definitions, some functional, some technological, and some benefits-oriented. A common element to most definitions is the application of digital processing andcommunications to the power grid, making data flow and information management central to the smart grid. Various capabilities result from the deeply integrated use of digital technology with power grids, and integration of the new grid information flows into utility processes and systems is one of the key issues in the design of smart grids. Electric utilities now find themselves making three classes of transformations: improvement of infrastructure, addition of the digital layer, which is the essence of the smart grid; and business process transformation, necessary to capitalize on the investments in smart technology. Much of the modernization work that has been going on in electric grid modernization, especially substation and distribution automation, is now included in the general concept of the smart grid, but additional capabilities are evolving as well.

1.2. Statement of the Problems

The Ethiopian government currently gives much emphasis to increase more generating units to balance with power demand without improvingthe reliability of power distribution system.There is virtually universal agreement that it is necessary to upgrade the electric grid toincrease overall system reliability. Much of the technology currently in use by the Ethiopian Electric utility isout dated and unreliable.Consequently, power interruption problem in thiscountry is very high and challenging.

Therefore, this leads the both the Utility and customer to be disturbed, hence high revenue loss. If this is not improved by use of protective devices or distribution generation, it can lead to the oversupply without selling what is expected. Due to the radial network topology of the power distribution system and unavailability ofcurrently in use protection devicesin power distribution system, the reliability of power distribution system is very low. In Bedele city power interruption frequency is 617 interruptions per customer per year and interrupted for 710 hour per customer per year due to feeder line faults. Similarly, for Bedele Brewery factory 272 failure per year and interrupted for 320 hour per year.

Thus, thepower distribution system reliability for the existing Bedele city network topology of EEUshould have to be critically analyzed and technology based measures towards reliability improvement should be implemented. Therefore, in this thesis Automatic recloser was incorporated into the existing system to improve the reliability of power distribution.

1.3. Motivation

Currently, Ethiopia is generating large amounts of power. Bedele city is one of the industrial and commercial centers of the region. But, the power is interrupted frequently and for a long duration of time. This occurs because of thefault section identification problem and unavailability of modern protection devices along the feeder. To get continuous power supplyit is necessary to improve the reliability of power distribution system. So my motivation is to minimize the large amount of unsold electrical energy due to power outage and safe the time of customersin Bedele city.

1.4. Objectives

General Objectives

The general objective of this thesis work is to improvethe reliability of Bedele city power Distribution system using protection device withETAP and DigSilent software.

Specific Objectives

- To assess the reliability performance of existing distribution network
- To estimate the economic impact of power interruption to utility and Brewery Factory
- To identify the specific protection device for Reliability Improvement options
- To evaluate reliability of power distribution system with protection devices
- To compare power distribution system with protection device and the existing
- Draw relevant conclusions and recommendations

1.5. Research Questions

At the end of the study the researcher was able to answer the following proposed research questions.

1. What is reliability performance of the existing power distribution system in the case study?
2. How reliability of power distribution system will be improved?
3. Is it possible to incorporate recloser in order to improve the reliability of power distribution system for the study area?
4. Why reclosers are used to improve reliability of power distribution system in Bedele?
5. What is the Reliability performance of the distribution network for selected scenario?

1.6. Scope of the Study

The scope of this research limited to assessing, analyzingand evaluating the reliability performance of the power distribution system without Recloser and with Recloser in order to improve the reliability of power distribution feeder of the selected case study using DigSilent and ETAP software.

1.7. Significance of the Study

The study will be useful for power distribution system planners, load forecasting and decision makers since it presents a concern on how much demand is available at each section of power distribution system and reliability performance of each section will be known easily. By minimizing unsold electrical energy EEU will benefits the corporation to earn more profit. The power distribution reliability of EEU should have to be investigated so that appropriate reliability improvement measures can be undertaken. Thus the result of this thesis work will be best inputfor those study groups and researchers who are working on the implementation of complex power distribution system.

1.8. Limitation of the Study

There are some limitations that have been faced in this study. The first limitation was some offices of EEU are not cooperative to give the recorded data because some data are recorded on hardcopy. The second limitation was because of the budget allowed by Jimma University is not enough for such thesis works it makes difficult to record unavailable data and change all hard copy data in to soft copy in order to make it ready for the software.

1.9. Thesis Outline

This thesis work consists of five chapters. The first chapter discuses about the introduction that is Background, Statement of the problem, Motivation, Objectives, Research Questions,Scope of the study, Significance of the study and limitation of the study. Chapter two looks theoretical back ground and different review literatures (books, journals and proceedings). Chapter three discusses about the methodology and data analysis of this thesis. Chapter four discusses about result and discussion of the Bedele power distribution systemwithout Reclosers and with reclosers. Chapter five includes conclusion and recommendation of the study for future work.

CHAPTER TWO

THEORETICAL BACKGROUND AND REVIEW OF LITERATURES

2.1.Reliability of Distribution network

2.1.1.Definition of Reliability

Distribution reliability primarily means continuation of power supply without interruption. IEEE 1366 standard defines distribution reliability as measurement of keeping lights on [3]. Simply, reliability is the measurement of equipment outage rates and power interruption duration. There are various events that disrupt normal operation of the distribution system leading to power outages. However, some key descriptions pertaining to distribution system reliability are explained below.

2.1.2.Bathtub Hazard Rate Curve

Reliability is defined as the probability that a component (or a system) will perform its intended function without failure for a specified period of time under designated operating conditions. Failure rate or hazard rate is an important function in reliability analysis because it provides a measure of the changes in the probability of failure over the lifetime of a component. In practice, it often exhibits a bathtub shape (see Figure 2.1). Reliability assessment includes selection of a reliability model, analysis of the model, calculation of the reliability performance indices, and evaluation of results, which includes establishment of confidence limits and decision on possible improvements.

The bathtub hazard rate curve shown in Figure 2.1is used to describe failure rate for many engineering components. The bathtub hazard rate curve may be divided into three distinct parts: (1) burn-in period, (2) useful life period, and (3) wear out period. During the burn-in period, the hazard rate decreases and some of the reasons for the occurrence of failures during this region are poor quality control, inadequate manufacturing methods, poor processes, human error, substandard materials and workmanship, and inadequate debugging. Other terms used for this decreasing hazard rate region are “infant mortality region”, “break-in region”, and “debugging region” [7, 8, 9].

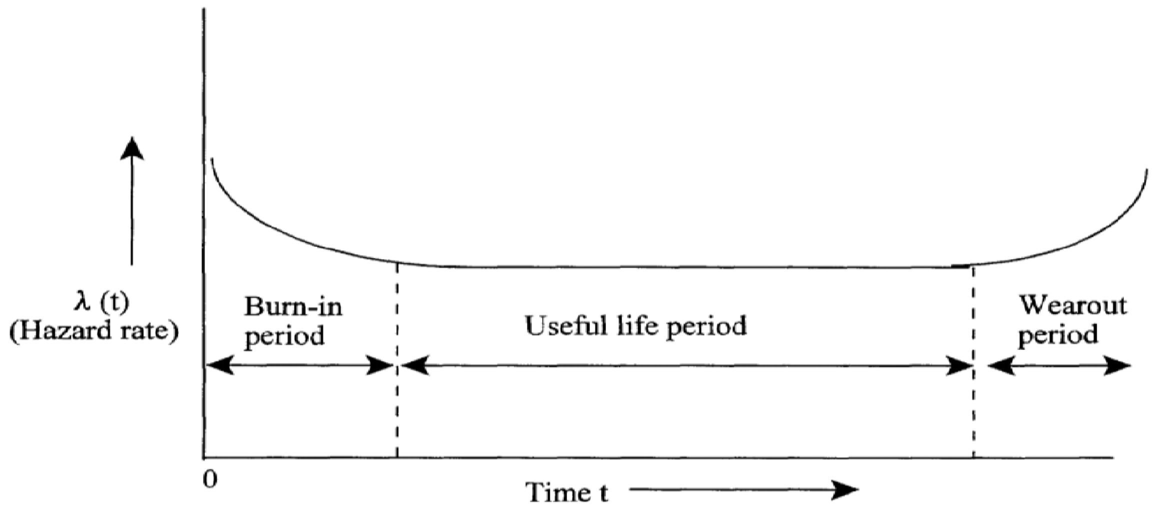

Figure2.1: Bathtub Hazard Rate Curve [7]

During the useful life period, the hazard rate remains constant and there are various reasons for the occurrence of failures in this region: undetectable defects, low safety factors, higher random stress than expected, abuse, human errors, natural failures, explainable causes, etc. During the wear out period, the hazard rate increases and the causes for the "wear out region" failures include wear due to aging, corrosion and creep, short designed-in life of the item under consideration, poor maintenance, wear due to friction, and incorrectoverhaul practices [7].

2.1.3. Momentary and Sustained Interruptions

Sustained interruptions are long-duration interruptions lasting longer than 5 minutes. Interruptions with a shorter duration (not exceed 5 minutes) are termed momentary interruptions [11]. Usually, only data on sustained interruptions is reported to the regulatory authority. Permanent faults on distribution circuits usually cause sustained interruptions to at least some customers.

Sustained interruptions can be classified as Planned and Unplanned Interruptions [5]. A planned interruption occurs at a selected time less inconvenient for the customers and the customers have been notified beforehand of the interruption. On the other hand, if the occurrence time of the interruption has not been selected, then the interruption is unplanned. Unplanned interruption occurs, for example, due to fault clearing, unwanted operation of the protection system or due to inadvertent initiation of opening operation of a switching device by a human. Planned interruptions occur mainly for the purpose of construction, preventative maintenance or repair.

Planned interruption: These are the interruptions during operation and maintenance of the system by informing the customers. It is also called operational (When outgoing lines are interrupted voluntarily for maintenance, circuit breaker oil change, load transfer, new transformer erection, etc.)

Unplanned interruption: These are interruptions due to the following causes offaults: (1) Distribution Permanent Earth Faults (DPEF), (2) Distribution Transient EarthFaults (DTEF), (3) Distribution Permanent Short Circuit (DPSC), (4) DistributionTransient Short Circuit (DTSC)and (5) Distribution line overload (DLOL).

Power Transformer Overload: Overloaded transformers are found in industry as a result of a combination of factors. Often times rapid plant expansion without adequate capacity planning can lead to overloaded transformers. This combined with the poor power factor and high harmonic currents generated by inductive loads, can cause a transformer to become heavily loaded. Whatever the cause, an overloaded transformer presents anobstacle to future plant expansion and heavily overloaded transformers can overheat and pose a potential fire hazard [6].

The description of the causes of unplanned interruptions is given below.
Earth fault: It is a conducting connection (whether intentional or accidental)between any electric conductor and any conducting material that is grounded or that may become grounded. Electricity always wants to find a path to the ground. In a ground fault, electricity has found a path to ground, but it is a path the electricity was never intended tobe on, such as through a person’s body [2].

The earth fault, caused by an insulation loss between a live conductor and an exposed conductive part, represents a plant engineering problem which may cause damage to the electrical installations and above all may jeopardize people; as a matter of fact, people could get in touch with an exposed-conductive-part not normally live but which, due to the fault, might have a dangerous potential to ground.

Short Circuits: It is the most commonly used term to describe the cause of a power failure. A short circuit occurs when an electric current travels along a path that is different from the intended one in an electrical circuit. When this happens, there is an excessive electric current which can lead to circuit damage, fire, and explosion. In fact, short circuits are one of the primary causes of electrical fires throughout the world [2].

Short circuits can occur when the insulation of the wiring used breaks down. It can also occur due to the presence of an external conducting material (such as water) that is introduced accidently into the circuit. Electrical batteries can explode if they are subjected to a large current. Short circuits can even occur when electric motors are forced to operate when the moving parts are jammed. This can result in abnormal buildup of current, ultimately leading to a short circuit.

Water can lead to short circuits and power failure. Because water is conductive so the current easily flows through it. Current will always take the easiest path. Since there is little resistance in water, the current will flow from positive to negative (or vice-versa) through the water causing the short circuit. The damage caused due to water in electrical circuits can be very expensive so it makes sense to ensure that you are well protected from it. Electrical switchboards, wires, and circuits should be protected from exposure to water. Dust can also wreak havoc with electrical systems and lead to short circuits and power failures.

Distribution Line Overload: Increasing demands for electric power have caused existingpower grids to become overloaded. Overloading is a common cause of line voltage fluctuations. Inadequate power generation and inadequate distribution systems are also causes of line voltage problems. Improper or poorly designed power regulating devices may create voltage fluctuations. Loose or corroded connections at the electric service user end can create voltage irregularities. The same conditions on the distribution power lines may also affect voltage. Many voltage fluctuation problems can be traced back to inadequate infrastructure [2].

The effects of power outages go beyond the annoyance experienced from the outage itself. In addition to being responsible for deaths and injuries when they interfere with elements of day-to-day life, outages pose a real public safety hazard. When an area of a city loses power, police and firefighters must be diverted from protecting neighborhoods to recovery operations and to make sure citizens are safe [8, 9].

2.1.4. Reliability Indices

There are many indices for measuring reliability. They are defined in IEEE Standard 1366[2, 10, 11, 13]. The indices for distribution analysis include customer-oriented indices andload or energy-oriented indices.

Three indices SAIDI, SAIFI and CAIDI are the main system indices used in the majority of countries. These indices are defined among others in IEEE Std.1366, where weighting based on number of customers is used. With both SAIFI and SAIDI, a reduction in value indicates an improvement in the continuity of supply. With CAIDI this is not the case. A reduction in both SAIDI and SAIFI could still result in an increase in CAIDI. Whereas CAIDI remains as a useful index although it is not suitable for comparisons or for trend analysis [27].

I. Customer-Oriented Indices

System Average Interruption frequency index (SAIFI)

SAIFI is the average number of interruptions per utility customer during the period of analysis and calculated by dividing the total number of customer interruptions with the total number of customer served by the network. It is usually measured over the course of a year. The expression for the calculation of SAIFI in IEEE Guide for Electric Power Reliability Indices [26] is as given by equation (2.1);

$$\text{SAIFI} = \frac{\sum_{i=1}^{n} Ni}{NT} \quad 2.1$$

Where;

N_i = number of customers affected by the i^{th} interruption

N_T= total number of customers served

Customer Average Interruption Frequency Index (CAIFI)

This index gives the average frequency of sustained interruptions for those customers experiencing sustained interruptions. The customer is counted once regardless of the number of times interrupted for this calculation.

CAIFI = $\frac{\text{Total Number of Customer interruption}}{\text{Total number of Customer affected}} = \frac{\sum(Ni)}{\sum(NT)}$ 2.2

System Average interruption duration index (SAIDI)

SAIDI is the average duration of all interruptions per utility customer during the period of analysis and calculated by dividing the sum of all customer interruption durations with the total number of customer served by the network. It is usually measured over the course of a year. The expression for the calculation of SAIDI in IEEE Guide for Electric Power Reliability Indices [26] is as given byequation (2.3);

SAIDI $= \frac{\sum_{i=1}^{n} tiNi}{NT}$ 2.3

where;

N_i= number of customers affected by the i^{th} interruption

t_i= duration of the i^{th} interruption

N_T= total number of customers served

Customer Average Interruption Duration Index (CAIDI)

It is the average time needed to restore service to the average customer per sustained interruption. It gives the average duration of a customer interruption and calculated by dividing sum of all customer interruption durations with the total number of customer interruptions. The expression for the calculation of CAIDI in IEEE Guide for Electric Power Reliability Indices [26] is as given by equation (2.4)**;**

CAIDI = $\frac{\text{Total Customer Interruption duration}}{\text{Total number of Customer interruption}} = \frac{\sum_{i=1}^{n}(tiNi)}{\sum_{i=1}^{n}(Ni)}$ 2.4

Where: tiduration of i^{th} interruption,N_i= number of customers affected by the i^{th} interruption

Average Service Availability Index (ASAI)

This index represents the fraction of time(often in percentage) that a customer has power provided during one year or the defined reporting period.

ASAI = $\frac{\text{Customer hour of available service}}{\text{Customer hour of demanded}} = \frac{\sum Ni*8760 - \sum UiNi}{\sum \lambda iNi*8760}$ 2.5

Where: Ui is the annual outage time at load point i and Ni is the number of customers atload point i.

Average Service Unavailability Index (ASUI)

This index is the complementary value to the average service availability index (ASAI).

$$ASUI = 1 - ASAI = \frac{\text{Customer hour of unavailable service}}{\text{Customer hour of demanded}} = \frac{\sum iUiNi}{\sum i\lambda iNi * 8760} \quad 2.6$$

Where: Ui is the annual outage time at load point i and Ni is the number of customers at load point i.

II. Load or Energy-Oriented Indices

Energy Not Supplied Index (ENS):- This index represents the total energy not supplied by the system.

$$ENS = \sum_i La(i)Ui \quad 2.7$$

Where: La(i) is the average load

Average Customer Curtailment Index (ACCI)

This index represents the total energy not supplied per affected customer by the system.

$$ACCI = \frac{\text{Total energy not supplied}}{\text{total number of customer affected}} = \frac{\sum iLa(i)Ni}{\sum iNo} \quad 2.8$$

Where: La (i) is the average load, No is the number of customers affected

A reliability index that considers momentary interruptions is Momentary Average Interruption Frequency Index (MAIFI) [10, 11]. MAIFI is the total number of customer momentary interruptions divided by the total number of customers served. Momentary interruptions are defined in IEEE Std. 1366 as those that result from each single operation of an interrupting device. The momentary interruptions are the interruptions that occur in a specified time not to exceed five minutes.

$$MAIFI = \frac{\text{Total number of customer momentry interruption}}{\text{Total number of customer served}} = \frac{\sum IDi * Ni}{NT} \quad 2.9$$

Where: IDi is the number of interrupting device operations, Ni is the number of customers experiencing momentary interruptions, and NT is the total number of customers served.

2.1.5. Economics of Reliability Assessment

Typically, as investment in system reliability increases, the reliability improves, but it is not a linear relationship [1]. By calculating the cost of each proposed improvement and finding a ration of the increased benefit to the increase cost, the cost effectiveness can be quantified.

Once the cost-effectiveness of the improvement options has been quantified, they can be prioritized for implementation. This incremental analysis of how reliability improves and affects the various indices versus the additional cost is necessary in order to help ensure that scarce resources are used most effectively.

Quantifying the additional cost of improved reliability is important, but additional considerations are needed for a more complete analysis. The costs associated with an outage are placed side by side against the investment costs for comparison in helping to find the true optimal reliability solution. Outage costs are generally divided between utility outage costs and customer outage costs.

Utility outage costs include the loss of revenue for energy not supplied, and the increased maintenance and repair costs to restore power to the customers affected. The maintenance and repair costs can be quantified as [5]:

$C_{m\&r} = \sum_{i}^{n} Ci + C\text{comp}$ 2.10

Where: C_i is the labor cost for each repair and maintenance action, and C_{comp} is the component replacement or repair cost

Therefore, the total utility cost for an outage is:

$.C_{outage} = (ENS)x(cost/kWh) + C_{m\&r}$

Where: ENS is the Energy Not Supplied.

While the outage costs to the utility can be significant, often the costs to the customer arefar greater. These costs vary greatly by customer sector type and geographical location.

Industrial customers: - have costs associated with loss of manufacture, damage equipment, and extra maintenance, loss of products and/or supplies to spoilage, restarting costs, and greatly reduced worker productivity effectiveness.

Commercial customers: -may lose business during the outage, and experience many of the same losses as industrial customers, but on a possibly smaller scale.

Residential customers:- typically have costs during a given outage that are far less than the previous two, but food spoilage, loss of heat during winter or air conditioning during a heat wave can be disproportionately large for some individual customers.In general, customer outage costs are more difficult to quantify. Through collection of datafrom industry and customer surveys, a formulation of sector damage functions is derivedwhich lead to composite damage functions.

The sector customer damage function (SCDF) is a cost function of each customer sector (industrial, commercial and residential customers). SCDF depict the sector interruption cost as a function of interruption duration. The composite customer damage function (CCDF), is an aggregation of the SCDF at specified load points and is weighted proportionally to the load at the load points [5]. For n customers,

$$CCDF = \sum_{i}^{n} Ci * SCDF \text{ cost/KW} \quad 2.11$$

Where: Ci is the energy demand of customer type i.

Therefore, the customer outage cost by sector is:

$$COST_i = \sum_{i}^{n} SCDF * L_i \quad 2.12$$

Where: Li is the average load at load point i.

Since the CCDF is a function of outage attributes, customer characteristics, and geographical characteristics, it is important to have accurate information about thesevariables. Although outage attributes include duration, season, time of day, advance notice, and day of the week, the most heavily weighted factor is outage duration.

The total customer cost for all applicable sectors can be found for a particular load point

From

$$COST_i = \sum_{i}^{n} CCDFi * L_i \quad 2.13$$

Or

$$COST_i = \sum_{i}^{n} Ci * SCDFi * L_i \quad 2.14$$

Since there is no classified customer sector and load data at each points it not possible to calculate customer outage cost in this Thesis.

2.1.6. Reliability Improvement options

Distribution utilities have a number of options available to improve the reliability of supply. These are: additional primary substations, additional feeder circuits, vegetation management using covered conductor, using underground circuits, feeder automation. Reliability gains can also made by increasing the protection capabilities. It also includes breaking the feeder into smaller segments. This reduces the number of customers per segment and, therefore, the number of customers that would be affected by a fault. Comparing above reliability improvement techniques, vegetation management and using protection device along the feeder is better option in terms of cost.Additionally, the faults on the rural overhead power lines are mostly caused by a transient nature effect such as animal contact, lightning stroke, wind and tree fall, etc. which can be solved by protection devices.

By knowing the root causes of faults, it is possible to take actions that will preventfaults from occurring, such as performing tree trimming, installing animalguards,executing inspection and maintenance plans. In addition to above preventive action it is better option for Bedele Distribution system to have protection system on the feeder line to improve reliability. The following are some of the protection devices used along the feeder line to improve the reliability of power distribution system and their operation principles.

I. Reliability improvement using Remotely-Controllable switches

These switches are used for general switching operations and, in the event of a permanent fault, an operator would use the FCI indication to determine which switches to open.Remotely-monitored Fault Current Indicators (FCIs) are used with the load-break switches; sometimes they are used separately, while sometimes they are built into the switch.When a permanent fault occurs, the following steps are taken:-

- The substation circuit breaker or recloser trips automatically to interrupt supply to the affected feeder.
- An operator in the control room:-

Identifies the faulty segment of the feeder by using the FCI indication displayed in the control room, opens the nearest upstream and downstream switches to isolate the faulty segment using the communications network, reconfigures the protection in substation breakers, closes the substation circuit breaker to restore power upstream of the faulty segment, Closes the normally-open tie point to provide power downstream of the faulty segment.Through this operation, power is restored to the healthy parts of the network. The operator would then dispatch the maintenance crews to the faulty segment of the feeder to remove the fault. Once theentire feeder is healthy, the operator would open the normally-open point and close the remotely controllable switches to restore the network to the normal pre-faulted configuration [24].

The reaction time of the control room has a significant impact on the feeder restoration times. In practice the reaction time is influenced by:the availability of an operator 24 hours per day, 7 days a week, sufficient staff of operators to monitor and react during periods of extreme fault activity such as large storms,reliability of communications network to monitor FCI indication and to control the switchgear, feeder complexity,level of automation in control room and network, If managed correctly, control room operations would not degrade the operational efficiency of this type of network. The disadvantage ofthis switchoperation is dependent on the integrity and availability of the communications network [24].

Manual and motor operated switches are the most basic type apparatus on the line. These are typically air break devices which are not typically designed for automatic operation and are for local (and occasionally remote) operation. The problem with switches is mostly time. [19].

II. Reliability improvement using Sectionalizers

A sectionalizing switch (Sectionalizer) is automatic load-break switch capable of monitoring both current and voltage on all three phases. The switch is combined with a controller that is capable of detecting through faults and upstream recloser operation.Fully featured sectionalizers offer improved fault detection and controller capabilities. The current sensors count the number of fault currents which pass through the switch, and the voltage sensors detect when the line is de-energized due to upstream recloser operation. When the programmed number of reclosing operations occurs, the controller opens the Sectionalizer during the dead time, to isolate the downstream faults.Upstream devices are set to open at a higher number of Supply Interruptions (SI) than the downstream devices[24, 19].

Basic operation during fault conditionswhen a permanent fault occurs, the following steps are taken:

> The substation circuit breaker or recloser trips and recloses automatically, while the sectionalizers count the supply interruptions.

> The first Sectionalizer to reach its set supply interruption(SI) count opens during the dead time of the recloser. This isolates the fault, and supply to the upstream portion of the feeder is restored automatically on the next reclose. The change of state in the Sectionalizer would then be reported via a communications network to the control room to fulfill the FCI function. An operator in the control room would then open the next downstream switch to isolate the faulty segment, reconfigure the protection in substation breakers if necessary, close the normally-open tie point to apply power downstream of the faulty segment [24].

Using Sectionalizer, feeder upstream from the fault is unaffected by communication problems. Sectionalizers are often used in locations where coordination with other devices is difficult due to tight coordination curves, or they can be used in place of fuses in high fault current areas (i.e., single or three phase taps near the substation) where it is difficult to coordinate with the fuse. In either case, Sectionalizers perform only as a feeder selective ("save the tap") arrangement, requiring the main line device to operate in order to open. This may be disadvantageous where there are critical loads on the main feeder, where a reduction in momentary average interruption frequency index (MAIFI) is important [19] [24].

III. Reliability improvement using Recloser

Reclosers are seen as the key Smart Grid building blocks available for fault detection, isolation and restoration programs in the distribution systems and the result of this fact has been an unprecedented increase of global demand for this product. A recloser offers a complete design solution with integrated smart grid capabilities offering not only remote control but automation and the analogue data measurement and logging capabilities to achieve the utilities business drivers [20].

Today's reclosers are capable of advanced protection, communication, automation and have additional analytical functionality. With an abundance of processing power at their disposal, utilities now have the flexibility to use the recloser as a stand-alone unit in a remote location, or to integrate several units into an automation system. Whatever the application, the reclosers are flexible enough to evolve with the utility's requirements. Reclosers monitor current, voltage, frequency and the power flow direction to protect the feeder. By coordinating the reclosers correctly, only the recloser that is the closest to the fault will trip. This is very important for the successful implementation of reclosers. A recloser can be programmed to automatically reclose when it tripped due to a fault.

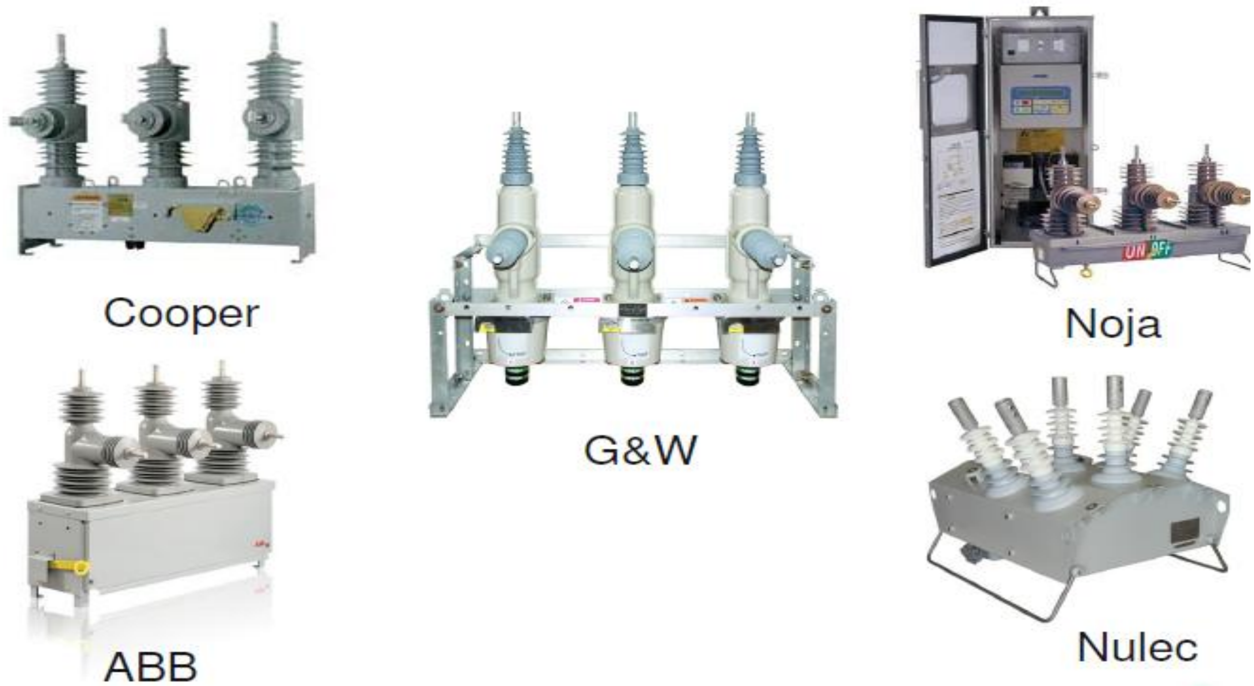

Figure 2.2: Different reclosers with their major manufacturer companies [24].

Auto-recloser is a protective device with the ability to detect phase and phase-to-earth overcurrent conditions, to interrupt the circuit if the overcurrent persists after a predetermined time, and then to automatically reclose to re-energize the line. They have ability to interrupt with minimum of 0.05 second and maximum closing time of 0.055 second. If the fault that originated the operation still exists, then the recloser will stay open after preset number of operations, thus isolating the faulted section from the rest of the system. In an overhead distribution system between 80 to 95 per cent of the faults are of a temporary nature and last, at the most, for a few cycles or seconds [32] [44]. Thus, the recloser, with its opening/closing characteristic, prevents a distribution circuit being left out of service for temporary faults. Typically, reclosers are designed to have up to three open-close operations and after these a final open operation to lock out the sequence.

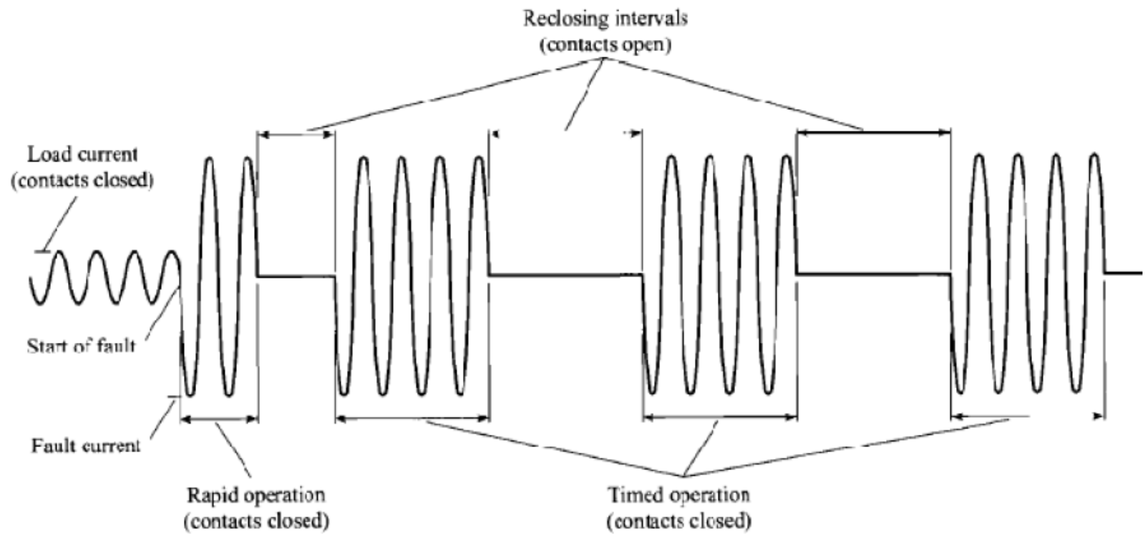

Figure 2.3:Typical Sequence for Recloser Operation [44]

Basic operation during fault conditions

It is possible to operate distribution network in either a “manual” mode where the operator has to perform the reconfiguration of the network or in a “Loop Automation” mode where the reclosers perform the entire task automatically.In the “manual mode” the following actions are taken:The recloser immediately upstream of the fault automatically trips, recloses to lockout and remains open. An operator: determines the location of the fault from the recloser status and/or additional FCIs opens the next downstream recloser to isolate the faulty segment; reconfigures the protection settings in anticipation of reverse power flow, and Closes the normally-open point to restore power downstream of the faulty segment.After fault cleared open the normally-open point, reconfigures, and closes the reclosers to restore the network to the normal pre-faulted configuration.

In a loop automation network the following actions will take place when a fault occurs:

>The recloser immediately upstream of the fault automatically trips, recloses to lockout and remains open.

>Reclosers downstream of the fault automatically change the protection settings in anticipation of power flowing in the opposite direction.

>The normally-open tie recloser closes automatically.

>Since the fault still being present, the recloser immediately downstream of the fault trips and locks out without reclosing.

This will automatically restore power to the healthy parts of the network. An operator can now dispatch line crews to the faulted segment. It is also possible for the loop automation system to restore the original configuration when the fault is cleared.

Communications are not required in the loop automation scheme. However, it may be desirable to do so in order to monitor the status of the network at several key points to assist maintenance crews. In a manual recloser system, the feeder upstream from the fault is unaffected by communication problems, but communication is required to reconfigure the downstream portion of the network and to control the normally-open point.

Today's reclosers are capable of sophisticated protection, communication, automation and analytical functionality. With an abundance of processing power at their disposal, utilities have the flexibility to use the recloser as a stand-alone unit in a remote location, or to integrate several units into sophisticated substation automation systems. Whatever the application, the reclosers are flexible enough to evolve with the utility's requirements. Reclosers monitor current, voltage, frequency and the power flow direction to protect the feeder. By coordinating the reclosers correctly only the recloser that is closest to the fault will trip. This is important for the successful implementation of reclosers. [22]. Taking into consideration above points this device must be implemented to improve reliability of power distribution system where faults aretemporary in nature.

IV. Reliability improvement using Fuses

The Expulsion fuses, installed in a fuse cut-out base, are used extensively in many utilitiesthroughout the world. These fuses provide a fairly low cost, yet effective, method for clearing fault current. Expulsion fuses are defined by their type and rating. The rating of a fuse refers to the continuous load current that the fuse can carry safely. It is, in other words, the highest current that can flow through the fuse, for an unlimited period, without damaging or melting the fuse. There is, however, a 'safety factor' of 2.25 included in the fuse rating because the fuse will in fact only start to melt at 2.25 times its rating. A fuse should however not be selected purely on its current rating, the TCC of the fuse must be used to ensure proper coordination with up and down stream protection devices [43].

Fuses are generally only used on lateral branches.When a fault occurs on the lateral line the fuse operates to clear the fault. When the fuse protection is graded correctly with the upstream recloser, the recloser will never need to operate on a lateral line fault. This means only the customers on the faulted lateral line experience an outage. The problem with this configuration is that the fuse blows on all faults, both permanent and transient, causing downstream customers to always experience a sustained outage and always requiring a line crew to replace the fuse incurring significant operating costs for the network owner. In most cases, this sustained outage is unnecessary as the fault is transient [40, 42].

A fuse that has blown will drop down and provide a visual indication to passing line crews as to the faulted line. When in the dropped down position the fuse provides a genuine electrical isolation due to the large air gap. Whilst fuses possess a low capital cost, up to 80% of fuses blow unnecessarily. Although fuses are quick and easy to install on site, a line man or crew, in an average rural environment may take hours to travel, patrol the line for potential fault, search for and repair the blown fuse, costing the utility lots of money for a single fuse operation. A fuse has no electronics or intelligence and, therefore, no capability to record historical data about fault events or reliability data. Without communication functionality, it cannot communicate device status remotely. It makes no contribution to the formation of an intelligent grid [42].

2.2.Literatures Review

Adegboyega Gabriel A.(2014)[36]:has done a paper in the title Reliability Analysis of Power Distribution System in Nigeria. In this paper reliability of power distribution system is studied by gathering outage data and evaluating system designs for three feeders. This paper shows the variation of the number of outages, their duration, basic reliability indices and Customer Orientation Indices over the period of study for each of the distribution feeders. But, this paper didn't include reliability improvement technique.

AdedayoKayodeBabarinde, Ayodele Sunday Oluwole, KehindeOlusuyi and TemitopeAdefarati published the paper in (2014) [15]:The result of this research illustrates that, the monthly number of outages and outage duration that occurred from month to month, 2012. As the calculated reliability indices shows reliability of case study vary from season to season. It suggests different protective devices such as circuit breakers, relays, current transformers and voltage transformers are one the method to increase system reliability. This paper proposes reliability improvement technique but doesn't use practically existing network model.

PremPrakash(2014)[33]: have shown that reliability of power distribution system can be improved by integration of Distribution Generation(DG).In this analysis Bus 2 of RBTS has been modeled in ETAP with its own data. A wind Turbine Generator is used as DG at different locations so that the variation in system reliability indices can be recognized with variation of distances from feeder. Here impact on reliability is most when it is placed farthest from feeder bus. This technique of reliability improvement depends on available renewable energy resource and it needs high investment cost.

AprajitaTripathi and ShilpiSisodia (2014) [35]: In this paper, Reliability Assessment Techniques are compared. By discussing three most common types of analytical technique these are State space, Contingency enumeration and Minimal cut set methods, this research recommends simplified contingency enumeration may use for reliability evaluation for power distribution system. In addition it illustrates two types of Monte Carlo simulation called sequential and non-sequential technique which are used to solve difficult reliability problems using random numbers. Finally, comparison result concludes that the indices are calculated in lower time and more accuracy using analytical technique. This research gives good information on which technique to use for reliability assessment. But, it hadn't proposed reliability improvement options.

C. Bhargava, P.S.R. Murthy and V. Krishna Murthy (2011) [25]:This paper has examined the impact of partial automation on reliability of distribution system. According to this journal result compared to the fully automation, the partial automation is economical. The reliability analysis shows that two- stage automation is an effective means to reduce the outage duration. The system reliability has increased considerably by automatic service restoration. With the implementation of the two- stage restoration on different feeders namely Urban, Rural and Industrial feeders the Energy not supplied will be decreased in case of industrial feeder due to less interruptions duration. It has shown that industrial feeders are highly reliable compared to urban and rural feeders.In general it shows reliability improvement depends on the way protection device along feeder is used.

A. Al-Abdulwahab (2007) [34]: has used genetic algorithm optimization technique in order to determine optimum placement of protection device using standard reliability data of each component and recorded customer data. For first case different reliability indices are used as a fitness function, as result different optimum location of recloser identified under each fitness function and repeated location is chosen. In the second case, for Sectionalizer optimum placement is done using SAIDI as objective function and others indices as constraint. For third case composite reliability indices is used as fitness function to determine optimum location of protection device. But the drawback of this system is it uses the evolutionary optimization techniques and the algorithm is only used to determine the optimal location of the protection device without considering protection coordination issue.

Generally, it is possible to say in one way or the other the above reliability analysis and improvement include: 1. Reliability of the distribution system doesn't improved well 2. Protection coordination didn't considered 3. Need communication infrastructure. The proposed ETAP model for reliability improvement of power distribution system using recloser avoids the above discussed issues.

CHAPTER THREE

METHODOLOGY ANDDATA ANALYSIS

3.1. Description of the Present Distribution system of Bedele City

Bedele city has been supplied from national grid. Ethiopian Electric Utility (EEU) is a provider of electric power in the country. A 132 kV incoming transmission line from Nekemte substation is stretched into the Bedele substation. Then, the distribution feeder in the city has a primary voltage of 15 kV. And also, this voltage value is stepped down to 380 and 220 volts to customer's level.

The network topology for Bedele city is radial grid. The protection device in the distribution system is circuit breaker at the substation for fault clearance. After fault location has been identified and fault area is isolated, the circuit breaker in the substation will be reclosed to energize the feeder lines for permanent faults. For distribution transformer there is drop out fuse to protect transformer from damage by over current. At low voltage side of transformer there is HRC fuse to protect from over current of low voltage side.

From Bedele substation there are 7 out-going feeder lines supplied from two power transformers. They are chora, Bedele city, Bedele Brewery factory, Alhabesh sugar Factory lines with 15KV andKolo sire, Chewaka,Dega lines with 33KV. Those feeder lines distribute power to different districts and location. So,studying the reliability of all distribution system at the same time is very difficult. Comparing the above lines Bedele city and Bedele brewery Factory line is chosen to be studied because it feed Business centers and industry compared to other feeders.

In this thesis, different literatures related to reliability of power distribution system are referred. Then necessary data are gathered from concerned organization. The collected data analyzed and reliability of existing power distribution system is assessed. Power distribution system with protection device along the feeder evaluated using ETAP software.Comparing scenarios using payback period, reliability performance and protection coordination simplicity. Therefore, using necessary collected data, which is analyzed in this chapter, this thesis conducted.

Table 3.1shows some feeder characteristics supplied from Bedele substation. Current transformer ratio and Power transformers are basic for relay coordination.

Table 3.1:Outgoing lines from Bedele Substation and some characteristics of feeder lines

Feeder name	Voltage level(KV)	Peak load (MW)	Average load (MW)	Length of feeder (KM)	CT Ratio	Power transformer rating (MVA)
Bedele city	15	2.12	1.3	110.59	100-200/5-5	12
Bedele brewery Factory	15	0.78	0.6	1.5	100-200 /5-5	12
Alhabesh	15	0.88	0.64	35	100-200/5-5	12
Chora	15	1.2	0.7	36	50-100 /5-5	12
Kolo sire	33	0.4	0.2	30	100-200/1-1	20
Chewaka	33	0.8	0.55	71.6	100-200/1-1	20
Dega	33	1.3	0.95	65.1	100-200/1-1	20

As demand increase from time to time it is necessary to check Current transformer ratio and relay settings. In the Table 3.1 Underlined primary CT ratio means it is already on operation value. For CT Ratio 100 – 200/5-5 means, this CT can be used either as 100/5 or 200/5. So, underlined200 value shows currently in service CT ratio from primary side.

These feeder lines interruption frequency and duration is highly annoying customers from time to time. Table 3.2 and table 3.3 shows feeder line relay report of the different faults. Each line interruption data is tabulated in the following tables. Based on interruption condition these data are classified as permanent, transient and planned interruption.

Table 3.2: Permanent, Transient and plannedinterruptions duration data in 2006 E.C

Name of the line	Interruption duration(hour/year)			
	Permanent fault	Transient Fault	Planned OP.	Total
Kolo sire	1865.34	31.41	63.78	1960.53
Dega	1931.56	76.72	289.6	2297.88
Chora	693	38.16	122	853.16
Alhabesh	1113.45	10.9	132.2	1256.55
Chewaka	1075.19	32.67	270.58	1378.44
Bedele city	492.85	105.44	46.28	644.57
Beer factory	108.55	20.32	13.7	142.57

From above table 3.2Dega line face highest interruption duration for permanent fault comparing to other lines. While Bedele brewery factory line face least interruption duration both for permanent and transient faults. Bedele city has highest Transient fault duration in this year.

Table 3.3:Permanent, Transient and planned interruptions frequency data in 2006 E.C

Name of the line	Frequency of interruption(Number of interruption per year)			
	permanent Fault	Transient Fault	planned Operation	Total
Kolo sire	243	94	18	355
Dega	443	188	121	752
Chora	186	88	53	327
Alhabesh	199	41	39	279
Chewaka	228	115	75	418
Bedele city	258	253	16	527
Beer factory	89	76	7	172

From above table 3.3 Dega line has highest frequency of interruption for permanent faults while Bedele city would face highest interruption frequency of transient faults. Beer factory faces least number of interruptions per year.

Table 3.4: Permanent, Transient and planned interruptions frequency data in 2007E.C

Name of line	Frequency of interruptions			
	Permanent Fault	Transient fault	Planned operation	Total
Kolo sire	362	169	24	555
Dega	368	175	115	658
Chora	221	153	104	478
Alhabesh	300	102	45	447
Chewaka	327	123	74	524
Bedele city	306	359	42	707
Beer factory	123	238	11	372

Dega and Kolo sire line have high permanent fault interruption frequency. Bedele city line has highest permanent fault interruption frequency. Next to Bedele city feeder, Beer factory would face highest interruption frequency.

Table 3.5: Permanent, Transient and planned interruptions duration data in 2007 E.C

Name of line	Interruption duration(Hr)			
	Permanent fault	Transient fault	Planned Operation	Total
Kolo sire	1862.49	46.407	88.58	1997.477
Dega	1518.65	73.89	256.06	1848.6
Chora	638.51	75.016	262.74	976.266
Alhabesh	1257.2	23.85	145	1426.05
Chewaka	1745.35	38.81	288.96	2073.12
Bedele city	226	471.68	76.9	774.58
Beer factory	424.8	63.35	9	497.15

As shown in the above table 3.5chewaka and Kolo sire line have high permanent fault interruption duration comparing to other lines. Interruption duration of Transient fault is higher than permanent faults for Bedele city feeder in this year. Longest time of power interruption duration happened at Kolo sire in 2007E.C.

Table 3.6: Average interruption duration and interruption frequency

Name of the line	Interruption duration		Average	Interruption frequency		Average
	2006 E.C	2007 E.C		2006 E.C	2007 E.C	
kolo sire	1960.53	1997.48	1979.0035	355	555	455
Dega	2297.88	1848.6	2073.24	752	658	705
Chora	853.16	976.266	914.713	327	478	402.5
Alhabesh	1256.55	1426.05	1341.3	279	447	363
Chewaka	1378.44	2073.12	1725.78	418	524	471
Bedele city	645	775	710	527	707	617
Beer Factory	143	497	320	172	372	272

Generally, studying Reliability of all these lines at same time is very difficult task due to unavailability of necessary data. So, as mentioned above this thesis focuses on Bedele city line and Bedele Brewery Factory line.

There are 50 distribution transformer connected to Bedele city feeder and two transformer connected to Bedele brewery factory loads (1200KVA and 1000KVA). The rating of each device is identified through field survey. There are three small towns that get power from Bedele city lines. These are Gachi, Yambero and yamfa.The collected data for Bedele city transformer are tabulated as follows.

Table 3.7: List of Distribution Transformers connected to Bedele city's feeder with their location village and rating.

No	Village Bedele City	Rating (KVA)	No	Village	Rating (KVA)	No	Village	Rating (KVA)
1	Substation	100	19	Mute	10	36	Mesgid	200
2	Dabena water	315	20	Sechomikeal	50	37	Kachise	100
3	Agriculture	100	21	EndeLibu	50	38	Administration	100
4	Gandi	100	22	Abdulatif	100	39	Medrock	100
5	TVET Tele	25	23	City water	630	40	Yohannis	100
6	TVET	200	24	Near Dashen	200	**Yembaro Town**		
7	KEC	200	25	Dashen	50	41	Jimma mewucha	315
8	Hospital	630	26	TenaTabiya	315	42	Yambero Tele	25
9	Administration	200	27	Tesema Tele	25	43	Medrock	100
10	Aba boku	315	28	Adebabay	200	44	Jimma Megbiya	315
11	Aratsemaniya	100	29	Kera Tele	25	**Yamfa Town**		
12	SengaTera	200	30	ECX	200	45	Police Tabiya	100
13	Tele office	100	31	Gebeya	200	46	Yamfa Mewucha	50
14	Waliya	100	**Gachi town**			47	MehalKetama	100
15	Dabo ber	315	32	Wuhalemat	50	48	TenaTabiya	50
16	High school Tele	25	33	Gachi tele	50	49	Yamfa Tele	25
17	Doro Erbata	100	34	TenaTabiya	200	50	Gebeya	100
18	Digeja Mariam	25	35	Rob gebiya	100			

The following is existing network topology of Bedele city and Bedele Brewery factory feeder line drawing. There are six manual fault section isolators called ‘senti’ to improve the reliability of the distribution system. Linecrews will open upstream senti after they identify fault area by searching or after customer inform them the fault location. Most of the time if fault happen at location where there is no customer, they are forced to search every sections to identify fault location.

1. Dabena water senti
2. Bedele city water Senti
3. Bedele- Gachi out-going senti
4. Gachi out-going Senti
5. Yembaro Senti
6. Yamfa senti

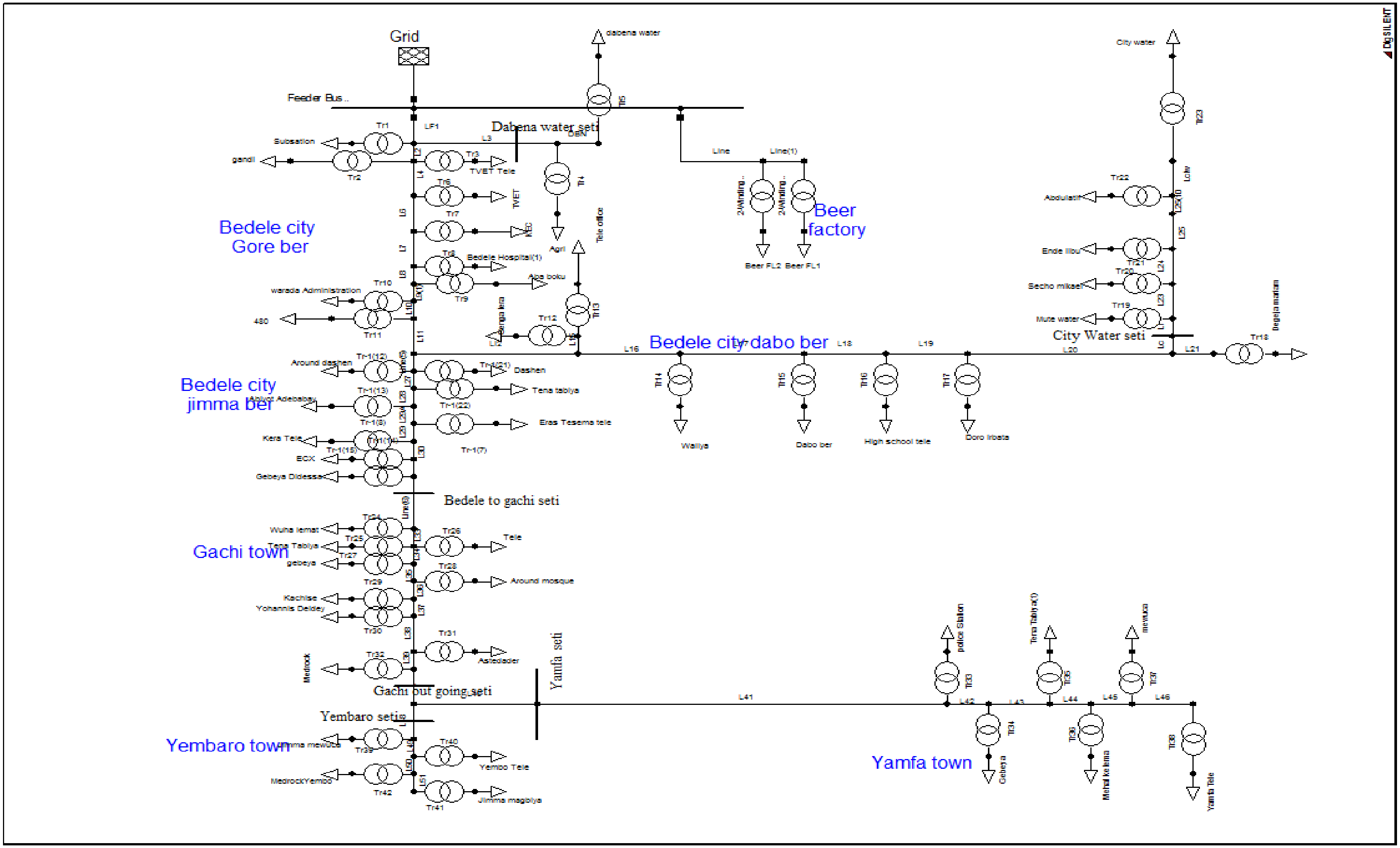

Figure3.1: Existing Radial network topology of Bedele city and Brewery factory Feeder line

As above radial feeder shows there are 50 distribution Transformers supplied from Bedele city line and 2 transformers for Bedele Brewery Factory. Through observation, the ratings of each transformer have been known. The exact average loading of each transformer is not known. Number of customer data for certain location is obtained from Bill code. Here is tabulated data for number of customer per section.

Table 3.8: Number of customersdata per section

Unit	Name of the section					
	Dabo ber	Jimma ber	Gore ber	Gachi	Yembaro	Yamfa
No of customers	1305	1420	1311	1017	297	603

Totally there are 5953 customers that get power from Bedele city feeder. This customer data hadn'tcategorized according to customer type.

Table 3.9: Average Hourly load data (MW) of the two feeders

Hour	Feeder name		Hour	Feeder name	
	Bedele city	Brewery Factory		Bedele city	Brewery factory
1	0.45	0.68	13	1.82	0.71
2	0.44	0.68	14	1.69	0.66
3	0.48	0.68	15	1.63	0.52
4	0.5	0.78	16	1.68	0.57
5	0.75	0.55	17	1.49	0.55
6	0.79	0.65	18	1.44	0.56
7	0.81	0.52	19	1.89	0.543
8	1.05	0.55	20	2.12	0.573
9	1.35	0.51	21	1.98	0.53
10	1.47	0.51	22	1.52	0.57
11	1.98	0.57	23	0.92	0.6
12	1.98	0.545	24	0.81	0.56

From above table the daily average load is 1.3MW for Bedele city and 0.6MW for Bedele Brewery factory.

Causes of interruptions are identified by Relay type and number trial of Circuit breaker to re-energize. In Bedele substation there are two analogue relay to send command to Line circuit breakers. These are over current and earth fault relay.

DTEF: - Indicated by earth fault relay. The Line is Re-energized by one or two trial of Circuit breakers.

DTSC: -Indicated by over current relay. The Line is Re-energized by one or two trial of Circuit breakers.

DPSC: - Indicated by over current relay. The fault can't be cleared by one or two trial of circuit breakers. It needs to solve existing fault to re-energize line again. After upstream senti disconnected from fault, the line will be energized.

DPEF: - Indicated by earth fault relay. The fault can't be cleared by one or two trial of circuit breakers in the substation. After upstream seti disconnected from fault the line will be energized.

DLOL: - Indicated on over current relay and display I>. Line will be energized after more 3 trials without identifying fault area. There is no recorded data of DLOL.

Here, in Bedele substation 15KV Feeder bus bar control relay is digital relay. The fault current stage of I>, I>> for phase faults and I_o>, I_o>> for earth faults arerecorded for every line interruption from Digital feeder relay report.

Table 3.10: The interruption duration [Hrs.]of both feedersfor each fault types per year

Name feeder	Year	Types of fault and their interruption duration per year				
		DPEF	DPSC	DTEF	DTSC	OP
Bedele Beer Factory	2006 E.C	27.28	81.32	3	17.32	13.7
Bedele Beer Factory	2007 E.C	272.2	152.6	8.32	55.03	9.15
Bedele city	2006 E.C	154	338.85	49.21	56.23	46.28
Bedele city	2007 E.C	18.55	207.45	11.25	460.08	76.9

In 2006 E.C and 2007 E.C Bedele brewery factory line face higher interruption duration for fault causes of DPSC and DPEF respectively. And Bedele city line faces higher interruption duration for fault causes of DPSC and DTSC in 2006 E.C and 2007 E.C respectively.

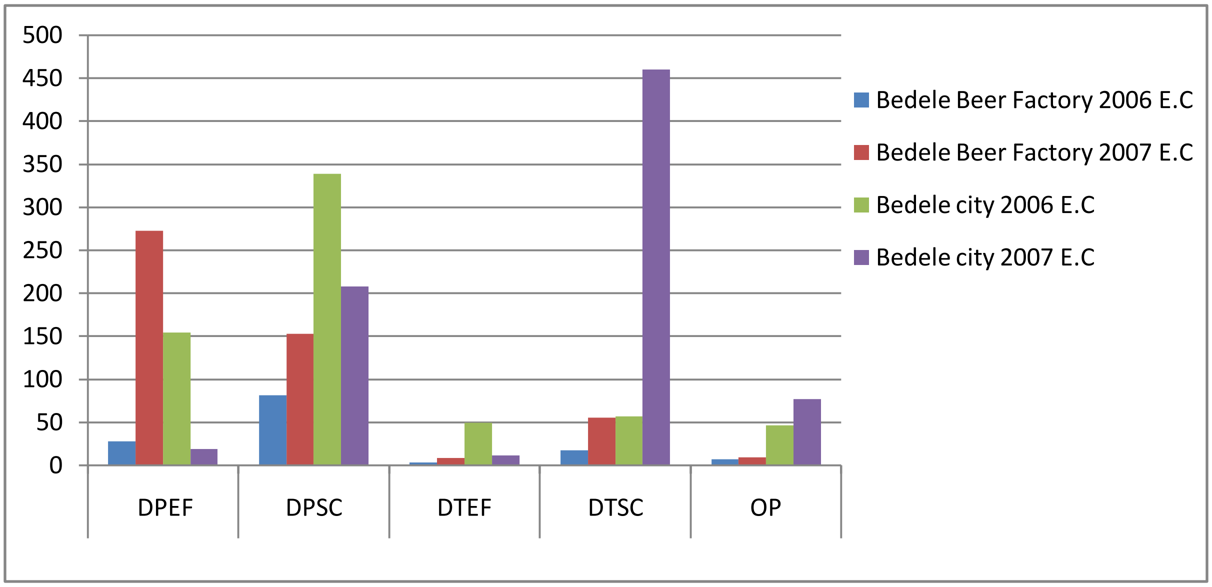

Figure3.2: Chart that shows relation between different faults causes for interruption duration

From above chartall fault types interruption duration increase in Bedele Brewery Factory feeder in 2007 E.C compared to 2006 E.C. But, for the Bedele city feeder power interruption duration for DPEF, DTSC and DTEF decreases in 2007 E.C compared to 2006 E.C. while interruption duration for DPSC and OP increased.

Table 3.11:Frequency of interruption of both lines for each fault types per year

Name feeder	Year	Types of fault and their interruption frequency per year				
		DPEF	DPSC	DTEF	DTSC	OP
Bedele Beer Factory	2006 E.C	22	67	4	72	7
Bedele Beer Factory	2007 E.C	55	68	20	218	11
Bedele city	2006 E.C	86	172	24	229	16
Bedele city	2007 E.C	10	296	5	354	42

As shown above Bedele brewery factory line faces higher interruption frequency for fault causes of DTSC for both years. Similarly, Bedele city line faces higher interruption frequency for fault causes of DTSC in each year. This shows that most faults are transient.

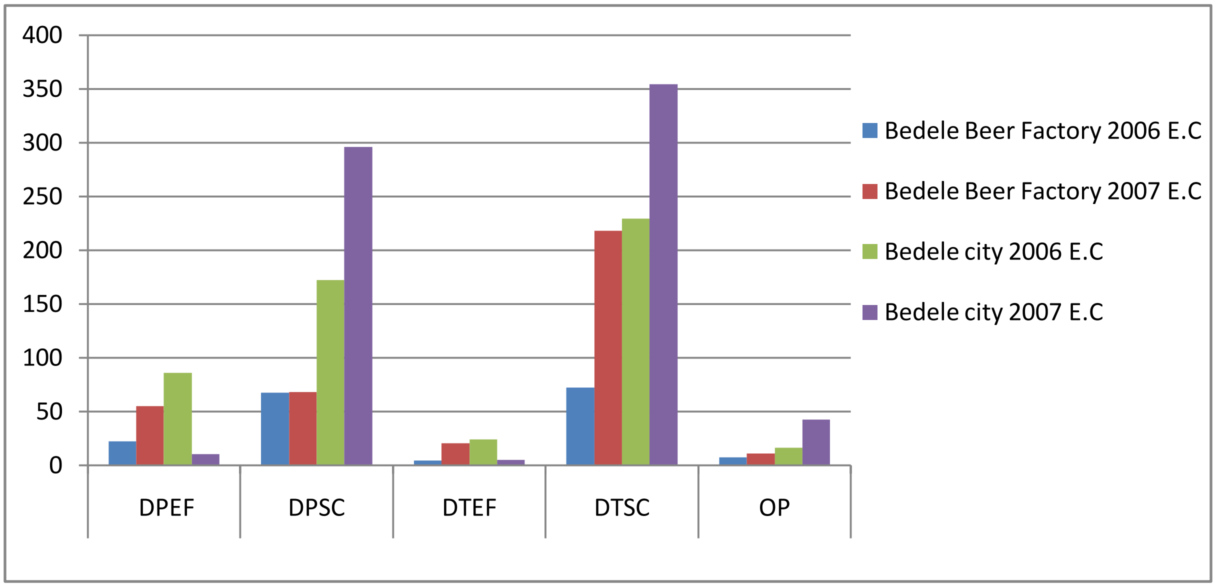

Figure3.3: Chart that shows relation between different fault causes for interruption frequency

As above chart indicates all fault types interruption frequency increase in Bedele Brewery Factory feeder in 2007 E.C compared to 2006 E.C. But for the Bedele city feeder power interruption frequency for DPEF and DTEF decreases in 2007 E.C compared to 2006 E.C. while interruption frequency for DPSC, DTSC and OP increased.

3.2. Reliability Indices Calculation

The reliability indices can be calculated using equations from (2.1) to (2.4) which are given in chapter two. Based on the data given in Table 3.2-3.5 we can calculate the reliability indices for each year. Similarly, it is possible to calculate the average reliability indices using the data given in Table 3.6.

To compare the basic Reliability indices of distribution system from Bedele substation, average interruption duration and frequency are used to tabulate data as follows.

Table 3.12: Average Reliability indices alloutgoing lines from Bedele substation

Name of line	SAIDI	SAIFI	CAIDI	ENS (MW)
Bedele city	710	617	1.15	923
Bedele brewery Factory	320	272	1.176	192
kolo sire	1979	455	4.35	792
Dega	2073	705	2.94	2,695
Chora	915	402.5	2.27	1,098
Alhabesh	1341	363	3.69	1,180
Chewaka	1726	471	3.66	1,381

From above table Dega line has long interruption duration (SAIDI) and high Energy not sold indices from given feeder lines. On each line there is vast reliability problem in the existing distribution system.

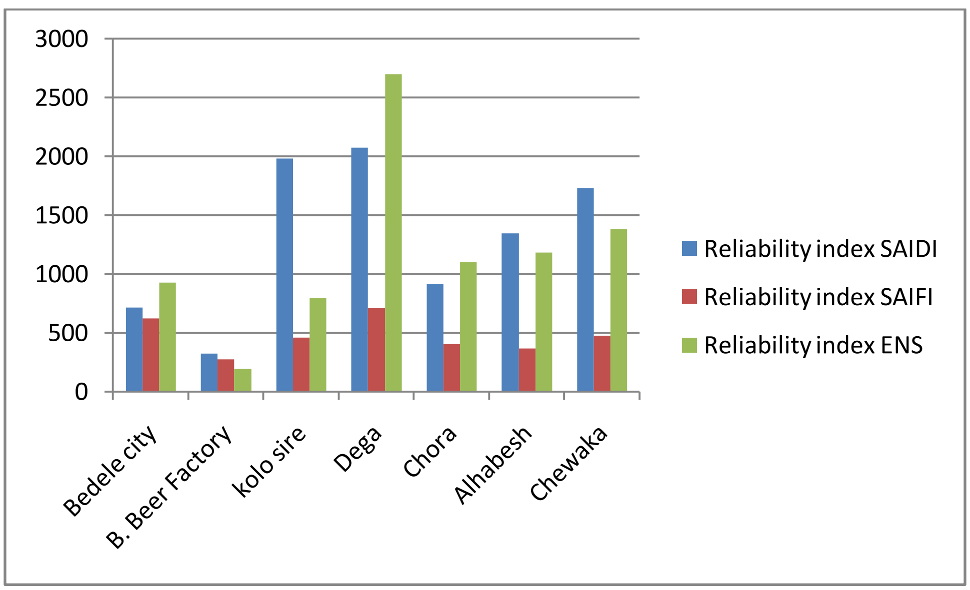

Figure3.4: Chart that shows relation between basic system and load reliability indices of all lines

SAIDI: It indicates the duration of interruption per customer per year. From Table 3.12the average SAIDI value of the Bedele city and Bedele Brewery Factory is 710 and 320 hours per customer per year respectively.This indicates that there is vast reliability problem in the existing power distribution system because according to Ethiopian Electrical Agency (EEA), the SAIDI value should not exceed 25 hours per customer per year [7]. And also, we can compare the calculated SAIDI value with the best experienced countries such as Germany. The maximum SAIDI value in Germany is 0.383 hours per customer per year [8, 9]. However, the calculated SAIDI value for the case under investigation is much greater than the standard of Germany. Therefore, Bedele power distribution system is unreliable.

SAIFI: It indicates the frequency of interruption per customer per year. The SAIFI values of the two feeders are 617 and 272 interruptions per customer per year as shown in Table 3.12. This Value indicates that there is vast reliability problem in the existing grid because according to Ethiopian Electrical Agency (EEA), the SAIFI value should not exceed 20 interruptions per customer per year [7]. And also, when we compare the calculated SAIFI value with the best experienced countries such as Germany, it is much greater than the maximum limit. Germany has a maximum of 0.5 interruptions per customer per year [8, 9]. Therefore, it indicates that the reliability problem in the present distribution system is clearly visible.

Table 3.13: Comparison of Reliability Indices of Bedele with best practice countries

Country		SAIFI(int/yr.cust)	SAIDI(int/yr.cust)
United state		1.5	4
Australia		0.9	1.2
Denmark		0.5	0.4
France		1.0	1.03
German		0.5	0.383
Italy		2.2	0.967
Netherlands		0.3	0.55
Spain		2.2	1.73
United Kingdom		0.8	1.5
Bedele	Bedele city	617	710
	Bedele Beer factory	272	320

Table 3.13 shows the comparison of the most commonly used reliability indices (SAIFI and SAIDI) of Bedele city and Bedele Brewery Factory distribution network with the requirements

of the Ethiopian Electric Agency (EEA) and the best experienced countries [7-9]. For instance, when we look at the SAIFI value of Germany, it is 0.5 interruptions per customer per year. This value indicates that the reliability of the power supply in Germany is the best. Similarly, the maximumSAIDI limit in Germany is 0.383 hours per customer per year. Hence, this reliability index also shows that the reliability of Germany power supply is the best as compared with the others.

The SAIFI value interruption per customer per year of the distribution system (Bedele city and Bedele Brewery factory) is 30.85 and13.6times the standard set by EEA respectively. Similarly, the SAIDI value in hour per customer per year of the distribution system (Bedele city) and (Bedele Brewery factory) is 28.4 and12.8 times the standard set by Ethiopian Electric Agency respectively. To improve this reliability problem, existing distribution system should employ proper reliability improving option.

3.3. Monetary Impact of Power Interruptions

The utility lost a large amount of revenue due to power outages. This outage cost include maintenance cost (fuel cost for fault location searching, labor cost, component replacement cost) and unsold energy cost. But, this thesis discusses only monetary impact due unsold energy. This revenue can be calculated using expected energy not supplied per year of the existing power distribution system given in Table3.14.

As discussed in section 2.1.5 customer outage costs are more difficult to quantify. Through collection of datafrom different sector and customer surveys, a formulation of sector damage functions is derivedwhich lead to composite damage functions. This function depends on outage attributes and customer characteristics of power distribution system. So, due to unavailability of necessary data this thesis is limited to estimating outage cost of Bedele Brewery from fuel expense and down time.

Table 3.14:Shows the Energy tariff of Ethiopian Electric utility [39].

Customers	Active Energy(KWh)	Price Rate(Birr/KWh)
Residential	0-50	0.2730
	51-100	0.3564
	101-200	0.4993
	201-300	0.5500
	301-400	0.5666
	401-500	0.5880
	Above 500	0.6943
Commercial	10-50	0.6088
	Above 50	0.6943
Industrial	15KV	0.4086

From above data, the range of revenue loss due to the unsold energy is:
[0.273 to 0.6943 Birr/kWh]*923,000.0 kWh = 232,323 to 590,849.3 Birr/year From Bedele city feeder line interruption. Hence the average unsold energy is 446,408.95 birr/year. Average Unsold energy is 115,200 birr/year from Bedele Brewery Factory. Thus, Average Unsold energy is 561,608.95Birr/year.

There is also revenue loss ofcommercial and residential customers due to the power outages. Since the analysis of all customers' revenue loss is difficult, the sample study is done by taking Bedele Brewery factory as a specific case study.Bedele Brewery is Government owned, under the control of the Federal Democratic Republic of Ethiopia Privatization and Public Enterprise Supervising agency. It is established in 1993. The factory produces 36,000 bottles of beer per hour. There is back up diesel generator with rating of 1250KVA forfactory in case of power interruption. The generator has power factor of 0.8 and it consume 200Lt fuel per hour.

Based on the production capacity of the factory, effort has been exerted to estimate the production loss due to the interruption of the power. Therefore, the following analysis isdone for the average interruption hours based on the data obtained from the Bedele substation and Bedele brewery factory. As mentioned above the rated capacity of the factory is 36,000 bottles per hour.

The Factory sell beer product minimum by 7.25 birr/bottle. If the factory were not using backup generator, the revenue loss would be high. Thus, using average rate production of 35,000bottles/Hr:-

Average production loss of Factory= 35,000bottles/hr*7.25birr/bottle*320interruption Hr/year

= 81,200,000Birr, which is very high power outage loss

But, to reduce this interruption revenue loss diesel generator is used. To estimate the cost expense due to fuel consumption: Existing Diesel generator that supply Factory has power factor of 0.8, consume 200Lt fuel per Hour.So,

Fuel expense = Consumption liter per hour *cost of fuel per liter* Average interruption duration

= 200Lt/hour*16.5birr/Lt*320hour

= 1,056,000 birr/year

The Factory is also using diesel generator for Dabena water (water pumping for Factory) with rating 175KVA. Fuel consumption of this generator is 400L/24Hr (16.67L/Hr). Similarly,

Fuel expense = Consumption liter per hour *cost of fuel per liter* Average interruption duration

= 16.67Lt/hour*16.5birr/Lt*710hour

= 195,289.05birr/year

Total cost expense due to fuel consumption = 1,056,000 birr/year + 195,289.05birr/year

= 1,251,289.05 birr/year

Using energy Tariff of Ethiopia Electric Utility for commercial customers = 0.6943Birr/Kwh,

If the power were supplied from grid for this time of interruption cost expense due to power consumption would be,

Cost expense from grid for Factory line interruption = 0.6Mw*320Hr*0.6943Birr/Kwh

=133,305.6birr/year

Cost expense from grid for Dabena load (Bedele city Feeder) interruption

= 140Kw*710Hr*0.6943Birr/Kwh

=69,013.42birr/year

Total cost expense from grid is = 133,305.6birr/year +69,013.42birr/year =202,319.02birr/year

Net expense fuel cost due to interruption is:-

=1,251,289.05 birr/year – 202,319.02birr/year

= 1,048,970.03Birr/Year

This shows that Factory is expensing 5.2 times cost while using from grid.Since, Factory is using manual Generator starting it takes to start product from 5 to 10 minutes. For 272 interruptions, on average 7x272 minutes or 31.7Hr interruption duration will be unproductive period for factory due distribution system power interruption.

Cost expense in unproductive period = 31.7x35,000Bottles/Hrx7.25birr/bottle

= 8,043,875 birr/year

The investment cost can be calculated by using the cost of total smart reclosers used todesign the system. Average cost of one Smart Recloser is $9,000 (USD) (Based on the currency exchange on May 20, 2016, $1 = 21.85 Birr) [23].Hence, the cost of one Smart Recloser is: 9,000*21.45 =193,050 Birr. The life time of the project is expected to be 25 years based on the smart reclosers and other accessories life time [1]. On the other hand, the payback period of the designed system for different cases is an important factor. Payback period is the length of time required to recover the cost of an investment. The payback period of a given investment or project is an important determinant of whether to undertake the position or project, as longer payback periods are typically not desirable for investment positions. The payback period in years can be calculated as:

$$\text{Payback period} = \frac{\text{Investement cost (birr)}}{\text{Annual saving (birr/year)}} \qquad 3.1$$

Thus, for the system which is designed by segmenting Bedele city feeder into different parts using auto recloser, the payback period can be calculated using equation above.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Reliability Evaluation of power Distribution system with reclosers

Defining Distribution Automation is somewhat like defining Smart Grid because if you askten different utilities you will likely get at least ten definitions.Distribution Automation Systems have been defined by the IEEE as systems that enable an electric utility to monitor, coordinate, and operate distribution components in a real time mode from remote locations. An electric power distribution system is an important part of electrical power systems in the delivery of electricity to consumers. Automation in the distribution field allows utilities to implement flexible control of distribution systems, which can be used to enhance efficiency, reliability, and quality of electric service [40, 41].

System reliability is clearly enhanced when automatic reconfiguration is provided without depending on communications. Decentralized communications is easily obtained with reclosers using a loop scheme. Communications is also a significant contribution to the overall restoration of the circuit, but is not required for immediate reconfiguration after a fault has occurred [21].Rather than automation of Power distribution systemwhich needs communication facilities and sensors,this case study is limited to use automatically fault clearing capability of protection devices.

Due to their reclosing capability and most faults in this case study is temporary in nature, reclosers are selected to improve reliability this power distribution system.There are two types of recloser currently in use. These are hydraulic and electronic reclosers. Electronic recloser is latest and has longer reclosing time. Unlike Hydraulic recloses, Min Trip is independent of the Reclosers continuous rating.Typical Reclosing intervals are 2, 5, and 15 seconds which is better than that of hydraulic reclosers. The minimum TCC Curve Separation between electronic reclosers must be greater than or equal to 0.30 second while between relay and electronic recloser is 0.25 second [39].

Over current (OC) and Earth fault(EF) protections are primary protection to medium voltage (MV)distribution lines. The pickup value for a relay is selected by considering maximum loading and transient current withstand capability of next protective device location while TMS (Time Multiplier Setting) setting is selected considering the maximum fault current at the location of protective device installed. Primary protection should recover the line from the fault within 1 s duration [30].

Relay pickup must be selected that it should not operate on the largest transient and short time current that can be tolerated by the system [30]. Therefore, two factors such as “short time maximum load” and “transient currents caused by switching operations on the power system” should be considered when selecting settings. Hence, Pickup of 125% - 150% of the maximum short time load or greater will be required to avoid operation on short time transients with inverse relay characteristics [29, 30, 31].

The factors that should be taken into account while designing the protection scheme are summarized as following: (1) load increase when protective devices were tripped, (2) fault current contribution factor from different sources, (3) coordination time interval insufficient for too many protection devices in series, (4) one device coordinating with two or more backups, and (5) bidirectional load current and fault current. Due to restriction of the coordination time interval (CTI) limit and the operating time requirement (general around30 cycles) for protecting the line near the substation, the number in series in one distribution line is limited also [37, 38].

Together with the coordination time interval (CTI) threshold between backup and primary devices, it is natural to understand that the CTI is insufficient for the protection devices in series.Generally, if we select a group of the TCCs, we can coordinate at most three reclosers in series. So, for this case study, up to three auto-reclosers can be installed in series and coordinated to reduce theamount of network affected by fault conditions[37].For placing of reclosers technical limitation of protection devices (protection coordination problem), location of load or customers (beginning of branches or sections and end of sections are best candidate for placing) and load types (sensitivity of load to interruption) are considered.

Different power distribution system simulation for reliability analysis is done using ETAP software. In ETAP the Distribution System Reliability Analysis employs a new analytical algorithm to assess the reliability indices of mixed radial and meshed distribution systems. This algorithm basically uses the algorithm for radial distribution systems since the meshed network, if any, is first converted to a radial network. Therefore, the employed algorithm is quite efficient and suitable for large-scale distribution systems of general configurations.This simulation result shows basic reliability indicator at each of section of the models.

In ETAP, Electric distribution system reliability analysis involves modeling different components of distribution systems, computing reliability indices at load points and for the overall system and ranking the elements that contribute to the load point/bus/system indices. Any switching device, such as breaker, fuse, contactor, and switch, has the function of fault isolation. Normally open tie circuit connections can be taken into account. Only an overcurrent protective device can interrupt fault currents. A fault in a radial sub-system is interrupted by the nearest overcurrent Protection device on its source side; a fault in a meshed sub-system is interrupted by its surrounding nearest overcurrent Protection devices. So, in this Thesis differentpower distribution model with recloser placements at different position is considered to study reliability improvement for Bedele city power distribution feeder.

4.1.1. Segmentation of feeder line using reclosers

Case-1: For Bedele city line without Reclosers (The existing power distribution system):Since probability of fault depends on the length of feeder line, the reliability this system modeled to be evaluated depending length of the line. Where ever fault happen along the feeder the whole customer would get interruption for existing network. Total feeder length 110.59 Km contribute to outage of power to all customers. But, for segmented feeder, any recloser is responsible for its section. So, probability of fault occurrence to each section depends on length of that section. For existing Power distribution network, Bedele city feeder is considered as a single section.The simulation result for existing power distribution system is shown below which verifies calculated indices values.

SUMMARY

System Indexes

SAIFI	617.0135 f / customer.yr
SAIDI	709.5701 hr / customer.yr
CAIDI	1.150 hr / customer interruption
ASAI	0.9190 pu
ASUI	0.08100 pu
EENS	923.405 MW hr / yr
ECOST	0.00 $ / yr
AENS	18.4681 MW hr / customer.yr
IEAR	0.000 $ / kW hr

Figure 4.1Simulation Summary report of Bedele city Distribution feeder line Reliability indices

<u>Case-2</u>: For Bedele city feeder with 2 Reclosers as shown fig. 4.4. These reclosers are located at Gore ber and Jimma ber exit.

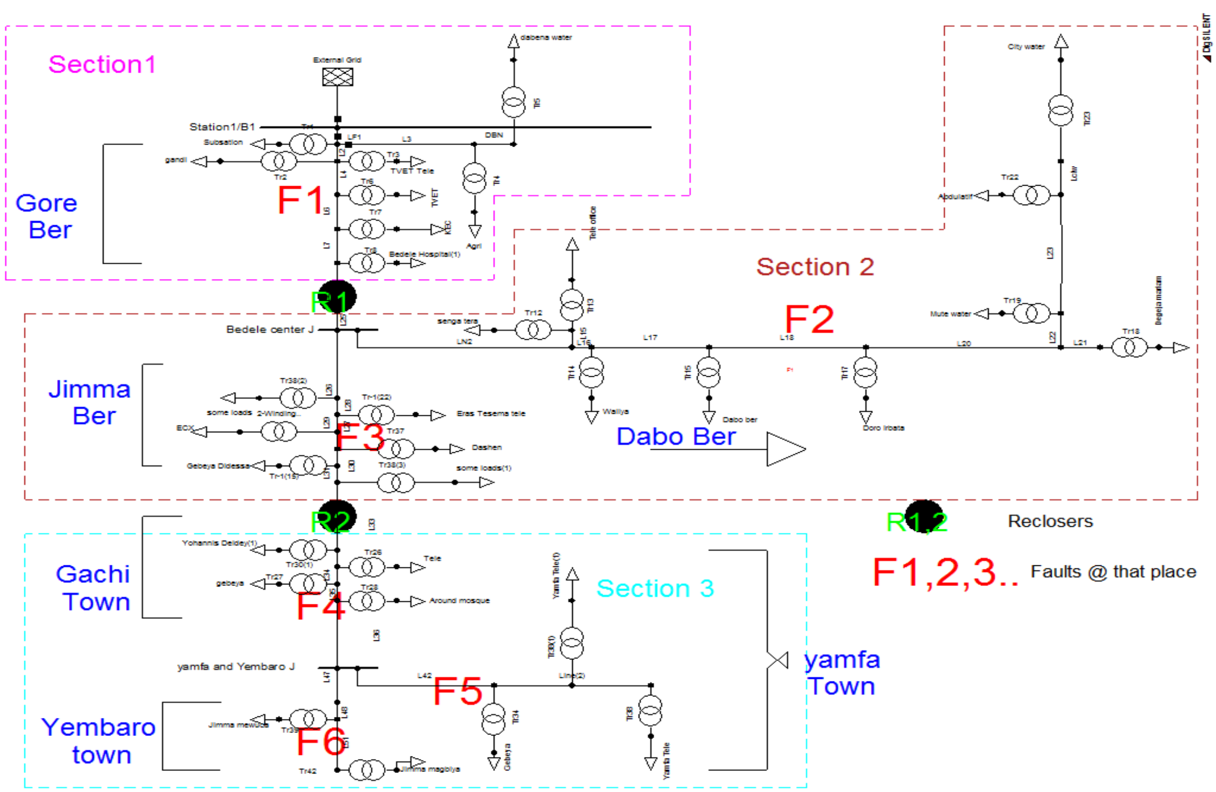

Figure 4.2: Distribution system model with two Reclosers using DigSilent power factory

This distribution line is segmented into three sections.

Section 1: In this section Circuit breaker is responsible to isolate the fault (F1). Here, each customer would face interruption duration of 56hr/yr and interruption frequency of 48int/yr.

Section 2: In this section Recloser 1 is responsible to isolate the fault (F_2 or F_3). Here, each customer would face interruption of 240hr/yr and 208int/yr.

Section 3: In this section Recloser 2 is responsible to isolate the fault (F4 or F5 or F6). Here, each customer would face 710hr/yr and 617int/yr. This shows that there are no improved reliability indices for 1917 customers in this section. The overall reliability performance of this model is shown in the following ETAP simulation result.

System Indexes

SAIFI	328.4887	f / customer.yr
SAIDI	377.7625	hr / customer.yr
CAIDI	1.150	hr / customer interruption
ASAI	0.9569	pu
ASUI	0.04312	pu
EENS	323.476	MW hr / yr
ECOST	0.00	$ / yr
AENS	6.4695	MW hr / customer.yr
IEAR	0.000	$ / kW hr

Figure4.3: SimulationSummary report of Bedele city Distribution feeder line Reliability improvement model using two reclosers.

Therefore, adding two reclosers as shown in above simulation result, the reliability of the overall has been improved. For instance, the frequency of interruptions and interruption duration of Bedele city line is 617 interruptions per yearand 710 hour per year respectively for existing system. When the line is segmented into two parts, the frequency of interruptions is reduced to 328 interruptions per year. While the duration of interruptions of Bedele city improved to 378 hours per customer per year. Energy expected not supply is also improved radically from 923Mwh/year to 323Mwh/year.

Case-3: In this model reclosers are located at Dabo ber, Jimma ber interance and Gachi town exit.

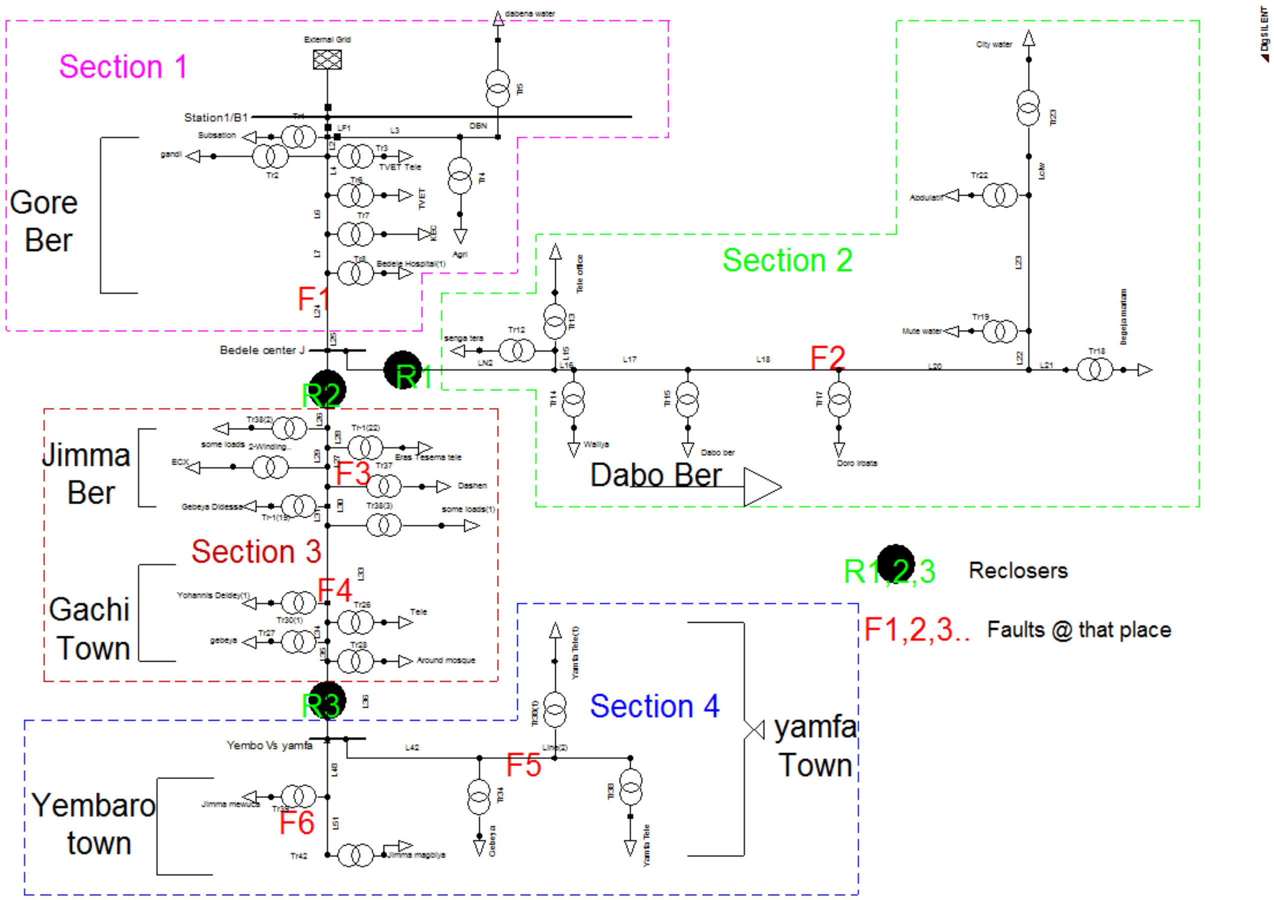

Figure 4.4:Distribution system model with three Reclosers using DigSilent power factory

This distribution line is segmented into four sections.

Section 1:In this section Circuit breaker is responsible to isolate the fault (F_1). Here, all customers on this feeder would face interruption of 56hr/yr and 48int/yr due to faults in region.

Section 2: In this section Recloser 1 is responsible to isolate the fault (F_2). Here, each customer in this section would face 221int.hr/yr and 192int/yr due to fault (F_2) in this region and other upstream faults.

Section 3: In this section Recloser 2 is responsible to isolate the fault (F3 or F4). According to this model each customer in this sectionand downstream would face 204int.hr/yr and 177int/yr.

Section 4: In this section Recloser 3 is responsible to isolate the faults (F5 or F6). According to this model each customer in this section would face 544int.hr/yr and 473int/yr due to these faults. The overall reliability performance of this model is shown in the following ETAP simulation result.

System Indexes

SAIFI	211.6822 f / customer.yr
SAIDI	243.4349 hr / customer.yr
CAIDI	1.150 hr / customer interruption
ASAI	0.9722 pu
ASUI	0.02779 pu
EENS	255.213 MW hr / yr
ECOST	0.00 $ / yr
AENS	5.1043 MW hr / customer.yr
IEAR	0.000 $ / kW hr

Figure 4.5: Simulation Summary report reliability indices value of case 3 model

By adding three reclosers as shown in above simulation result, the reliability of the overall has been improved. For instance, the frequency of interruptions and interruption duration of Bedele city line is 328 interruptions per year and 378 hour per year respectively in case 2. When the line is segmented into four parts, the frequency of interruptions is reduced to 212 interruptions per year. While the duration of interruptions of Bedele city feeder improved to 243 hours per year. Energy expected not supply is also improved from 323Mwh/year to 255Mwh/year.

Case-4: Again further segmentation of feeder is considered using four normally closed Reclosers. In this model reclosers are located at Dabo ber, Jimma ber interance, Jimma ber Exit, and Gachi town exit.

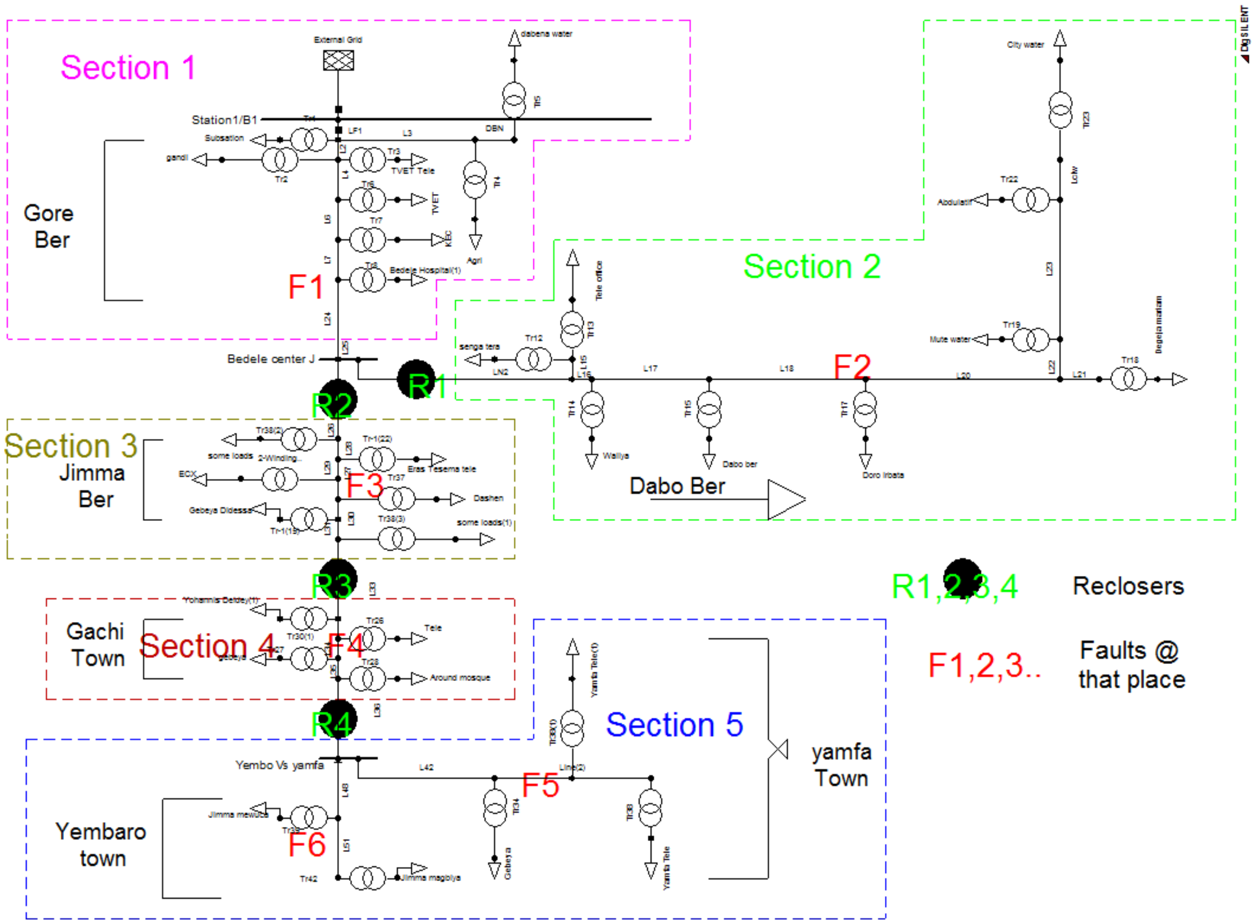

Figure 4.6:Distribution system model with four Reclosers using DigSilent power factory

This distribution line is segmented into five sections.

Section 1: In this section Circuit breaker is responsible to isolate the fault (F_1). Here, all customers on this feeder would face interruption duration of 56hr/yr and 48int/yr due to faults in region.

Section 2: In this section Recloser 1 is responsible to isolate the fault (F_2). Here, each customer in this section would face 221int.hr/yr and 192int/yr due to fault (F_2) in this region.

Section 3: In this section Recloser 2 is responsible to isolate the fault (F3). According to this model each customer in this section would face 76int.hr/yr and 65int/yr due to fault in this section and upstream.

Section 4: In this section Recloser 3 is responsible to isolate the fault (F4). According to this model each customer in this section would face 204int.hr/yr and 177int/yr due to faults in this section and upstream.

Section 5: In this section Recloser 4 is responsible to isolate the faults (F5 or F6). According to this model each customer in this section would face 544int.hr/yr and 473int/yr due to these faults. The overall reliability improvement of this model is shown in the following ETAP simulation result.

System Indexes

SAIFI	193.6788 f / customer.yr
SAIDI	222.7296 hr / customer.yr
CAIDI	1.150 hr / customer interruption
ASAI	0.9746 pu
ASUI	0.02543 pu
EENS	239.943 MW hr / yr
ECOST	0.00 $ / yr
AENS	4.7988 MW hr / customer.yr
IEAR	0.000 $ / kW hr

Figure4.7: Simulation Summary report reliability indices values of case4 model

By adding four reclosers as shown in above simulation result, the reliability of the overall has been improved. When the line is segmented into five segments, the frequency of interruptions is reduced to 194 interruptions per year. While the duration of interruptions of Bedele city feeder improved to 223 hours per year. Energy expected not supply is also improved to 255Mwh/year.

<u>Case-5</u>: Bedele city feeder with four Reclosers

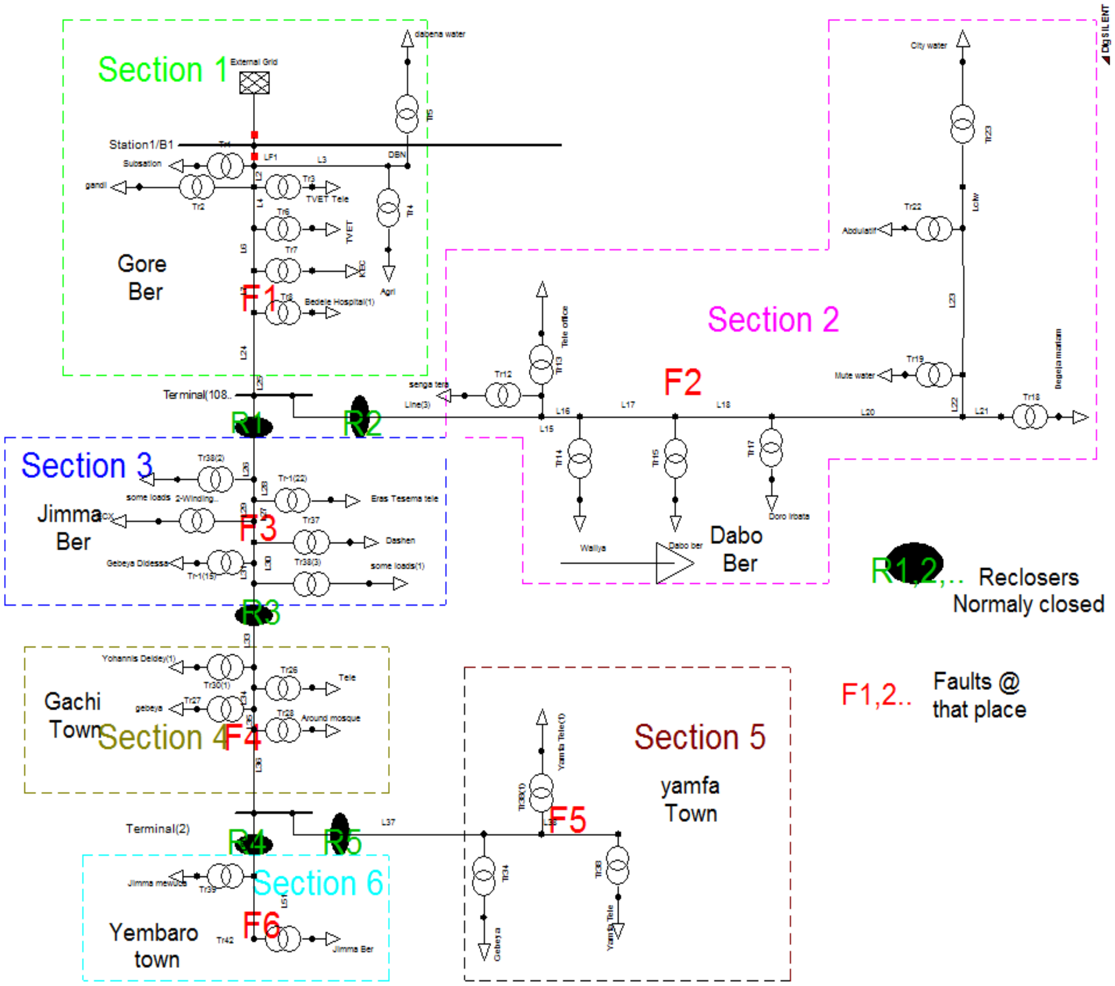

Figure 4.8:Distribution system Model with five Reclosers using DigSilent power factory

This distribution line is segmented into six sections.

Section 1: In this section Circuit breaker is responsible to isolate the fault (F_1). Here, all customers on this section would face 56hr/yr and 48int/yr due to faults in thissection.

Section 2: In this section Recloser 2 is responsible to isolate the fault (F_2). Here, each customer in this section would face 221int.hr/yr and 192int/yr due to fault (F_2) in this region and upstream.

Section 3: For this section Recloser 1 is responsible to isolate the fault (F3). According to this model each customer in this section would face 76int.hr/yr and 65 int/yr due to fault (F3) in this section and upstream.

Section 4: For this section Recloser 3 is responsible to isolate the fault (F4). According to this model each customer in this section would face 237int.hr/yr and 206int/yr due to fault in this section and upstream.

Section 5: In this section Recloser 5 is responsible to isolate the faults (F5). According to this model each customer in this section would face 442int.hr/yr and 384int/yr due to faults.

Section 6: In this section Recloser 4 is responsible to isolate the faults (F6). According to this model each customer in this section would face 442int.hr/yr and 384int/yr due to these faults. The overall reliability improvement of this model is shown in the following ETAP simulation result.

SAIFI	173.9805 f / customer.yr
SAIDI	200.0765 hr / customer.yr
CAIDI	1.150 hr / customer interruption
ASAI	0.9772 pu
ASUI	0.02284 pu
EENS	228.241 MW hr / yr
ECOST	0.00 $ / yr
AENS	4.5648 MW hr / customer.yr
IEAR	0.000 $ / kW hr

Figure 4.9: Simulation summary report reliability indices values of case5 model

When the number of segments is increased by using additional reclosers, the reliability of the system will be improved more. Therefore, according to above different distribution system with different number of reclosers, when the numbers of sections are three (3) and two (2) reclosers, the reliability improvement is 47% (for SAIFI and SAIDI) and 65% for EENS. And also, when the numbers of sections are four (4) and three reclosers(3), the reliability indices will beimproved by 66% (for SAIFI and SAIDI) and 72% for EENS. Similarly, when the numbers of segments are five (5) and 4 reclosers used the reliability is improved by 69% (for SAIFI and SAIDI) and 74% for EENS. The last segmentation model shows that radial feeder of Bedele city segmented into six (6) section using five (5) Reclosers, the reliability indices will be improved by

72%(SAIFI and SAIDI) and 75% for EENS. So, this shows that further segmentation of radial feeder using protection device improve reliability of the distribution system.

From above cases reliability indices of distribution system improved with different percentage. Reliability improvement of above five cases is tabulated as follows.

Table 4.1: Basic system and load reliability indices value for each segmentedcases

Cases	No of segment	Number of recloser	Reliability Indices			
			SAIFI	SAIDI	CAIDI	ENS(MWh)
1	1	0	617	710	1.15	923
2	3	2	328	378	1.15	323
3	4	3	212	243	1.15	255
4	6	4	194	223	1.15	240
5	7	5	174	200	1.15	228

The above Table show the reliability indices which areevaluated using the active failure rate in number of failures per year per unit lengthand mean time to Repair of the designed distribution system using reclosers. Therefore, reliability improvements can be summarizedas follows.

SAIFI: - Based on the data which is found in above table, the SAIFI value of the overall system is improved by 47% -72%. Therefore, this value indicates the reliability of the existing grid is improved using auto reclosers for power distribution system.

SAIDI: - The SAIDI value of the overall system is improved by 47%-72%. Therefore, the reliability of the existing is improved.

CAIDI: - It is the average duration of an interruption, calculated based on the total number of sustained interruptions in a year. It is the ratio of the total duration of interruptions to the total number of interruptions. Since both the duration of interruptions (SAIDI) and frequency of interruption (SAIFI) are reduced by the same percentage, their ratio (CAIDI) is the same for both the designed distribution system and existing grid. Therefore, the CAIDI value for all cases is 1.15 hours per interruption.

ENS: - It indicates the unsold energy of each feeder. The ENS value of the existing grid is 923,000 kWh. This value is reduced to 200,000 kWh for case 5 model.

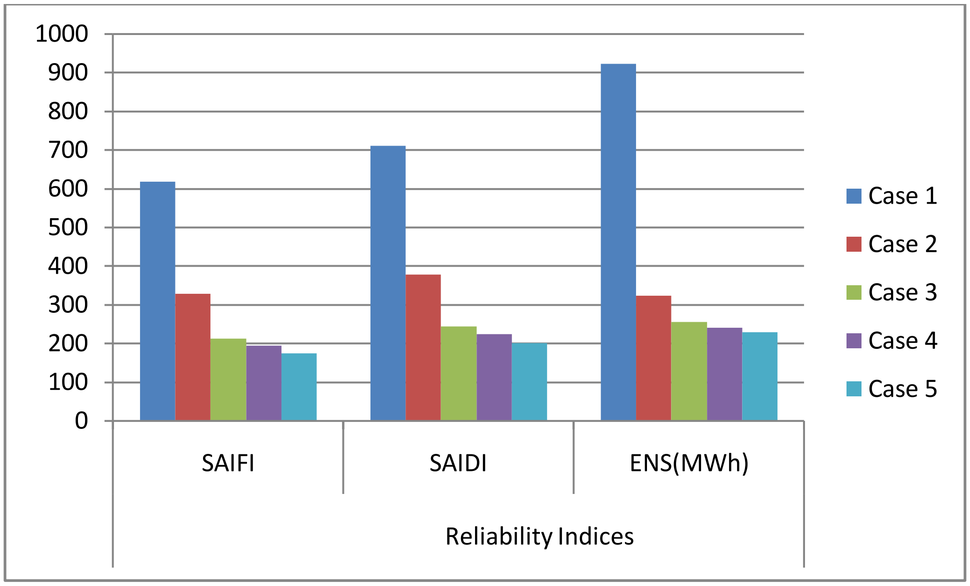

Figure 4.10: Chart that shows Reliability indices improvement by segmentation of feeder linefordifferent models

As shown in above figure 4.10 reliability indices changed radically from case 1 to case 2 models. Again there is significant improvement from case 2 to case 3 on all indices. But, from overall models Case 4 and Case 5 have better reliability performance from feeder segmentation scenarios.

4.1.2. Auto restoration with open tie recloser

Another distribution line in Bedele city is Bedele brewery factory line which is 1.5Km long.The line segmentation is used to minimize the number of customers affected and minimize the time required to patrol the line and locate the fault.Segmentation of this feeder doesn't improve customer hour interruptions along the feeder since it is short line and supply only one customer. So, to improve reliability of this feeder reducing the factors of reliability problem is main solution. In addition, this thesis proposes Reconfiguration of this line with alternate feeder line.

When the number of segments is increased by using additional reclosers, the reliability of the system will be improved more [4, 18]. In order to have auto restoration there must be alternate feeder to connect to another feeder for reconfiguration of after fault.Auto restoration or reconfiguration using open tie Recloser improve reliability of distribution system. It improves basic Reliability indices like SAIDI and ENS by reducing interruption duration of power distribution system.

Here, in Bedele city the feeders supply different direction loads. So, it very is expensive to reconfigure feeder with tie switch since it need long distribution line construction. However, there is possibility of connecting to Bedele Beer Factory with Bedele city feeder via Dabo ber lateral line. So, loop automation with Bedele Brewery factory is considered in this paper. In order to avoid reliability disturbance of Bedele Beer Factory due to looping, normally open recloser and Automatic switch should be placed close to Factory. Four alternative cases for auto restoration of Bedele city radial feeder with Bedele brewery factory feeder can be evaluated using open tie recloser via dabo ber lateral line.

As stated in section 4.1 the protection device recloser is placed depending on technical limitation of protection devices (coordination time interval limit), location of load or customers (beginning of branches or sections and end of sections are best candidate for placing) and load types (sensitivity of load for interruption) are considered. In order to reduce investment cost and protection coordination problem auto Sectionalizer can be used at gore ber and on Brewery factory line near to factory instead of recloser since both have same reliability improvement contribution here. That means whether recloser or Sectionalizer placed at this location they have function of fault area isolation while downstream load supplied from alternate line.

<u>Case A</u>

By adding two reclosers on radial distribution system modeled in case 1, it is possible to model auto power restoration. In this model there are 4 sections. Protection devices are located at Gore ber, jimma ber exit, near Beer factory from Substation side and 1 normally open recloser to tie with city feeder. Recloser1 (R1) and Sectionalizer (S1) have role of isolating fault section, if fault happened in section 1 and section 4 respectively. In addition, R1 is responsible for interruption faults may happen in section 2. In order to reduce investment cost, auto Sectionalizer (S1) is used instead of recloser.

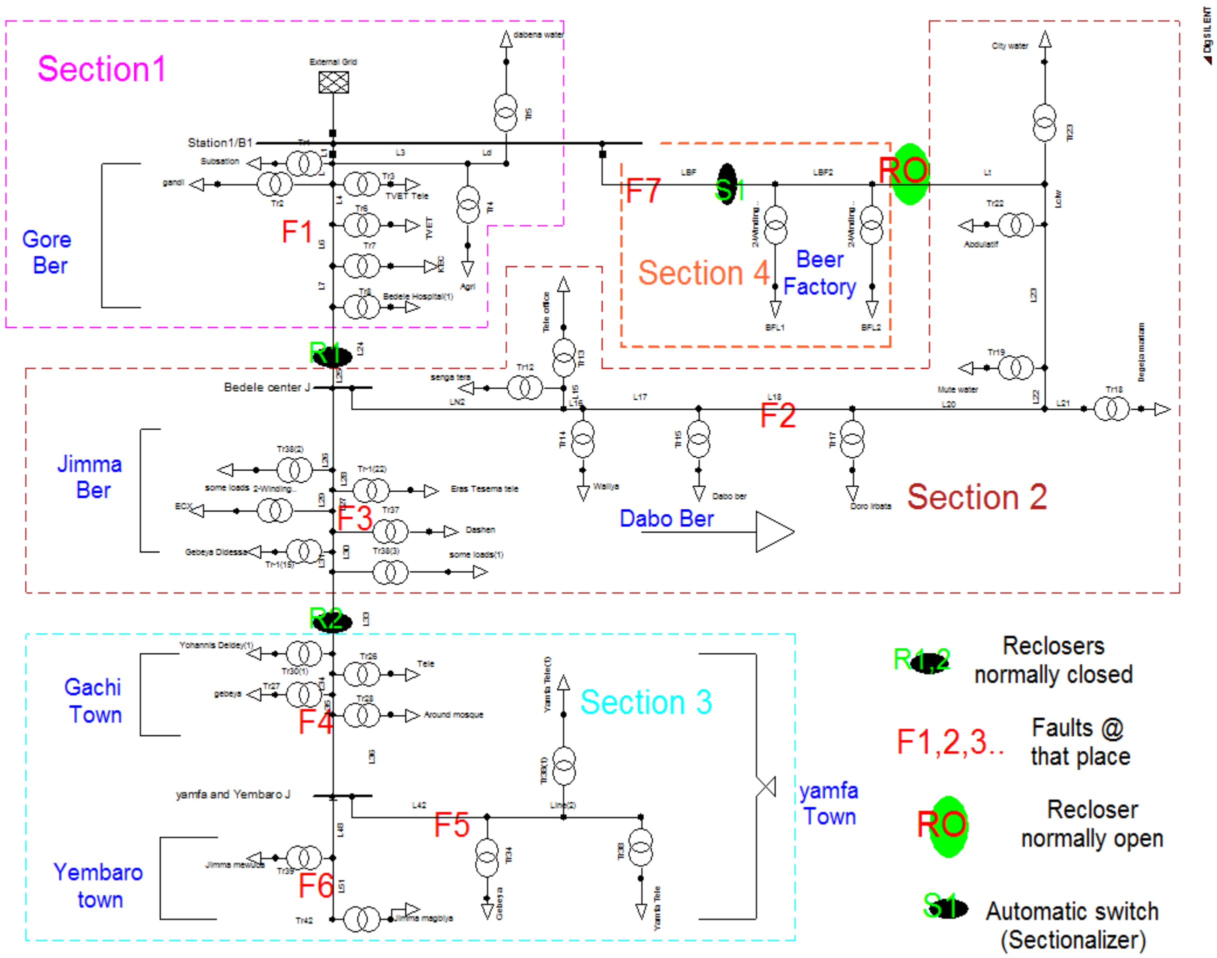

Figure 4.11: Auto Restoration of Bedele City and Bedele Brewery factory distribution system network model using three reclosers and one Sectionalizer

Auto restoration improves ENS and SAIDI of this Distribution system. The extent ENS index improvement depends on the section load that restored by tie recloser. If Restored section has high average load, ENS index will highly improve compared to restoring lightly loaded section. Similarly SAIDI improvement depend on length of Feeder restored.

Section1: when fault happen this section, circuit breaker in the substation will trip. Restoration power from Beer factory can supply other section except section 1.

Thus, According to this model 56 int.hr/customer/yr and 48 f/customer/yr will occur in this section.

Section2: fault in this section is controlled by two reclosers. When fault occur in normal operation condition (supplying section from city line) Recloser 1 will clear that fault. If fault happen in section 1 and this section is on maintenance time, section 2 and downstream load will get power via Beer factory line. So, at this time normally open recloser (Ro) will isolate the faults. According to this model 184 int.hr/customer/yr and 208f/customer/yr will occur in this section.

Section3: when fault happen in section this section recloser 2 will clear the fault. But, this fault affects 3 rural towns. These are Gachi,Yembaro and Yamfa. According to this model 654 int.hr/customer/yr and 617 f/customer/yr will occur in this section. Failure frequency for these towns hadn't improved.

Section 4: when fault occur in this section circuit breaker in the substation that control the Bedele beer factory line will trip. According to this model 0.38 int.hr/yr and 272 f/yr will occur in this section. Even though, there is frequently interrupted power the same as existing power distribution system in this section, interruption duration is negligible due to auto restoration

System Indexes

SAIFI	326.3003 f / customer.yr
SAIDI	321.7132 hr / customer.yr
CAIDI	0.986 hr / customer interruption
ASAI	0.9633 pu
ASUI	0.03673 pu
EENS	271.681 MW hr / yr
ECOST	0.00 $ / yr
AENS	5.2246 MW hr / customer.yr
IEAR	0.000 $ / kW hr

Figure 4.12: Simulation summary report of power distribution system using open tie recloser for case A

Case B

In this model there are 5 sections. Protection devices are located at Gore ber, Dabo ber,inter jimma ber, Gechi outgoing and near Beer factory from Substation side and 1 normally open recloser to the tie two feeders. The role of Protection devices located at Gore ber and near Beer factory to Substation side is isolating faulty section. In order to reduce investment cost and protection coordination problem, these protection devicesshould be auto Sectionalizers (automatic switch) while others protection device are reclosers.

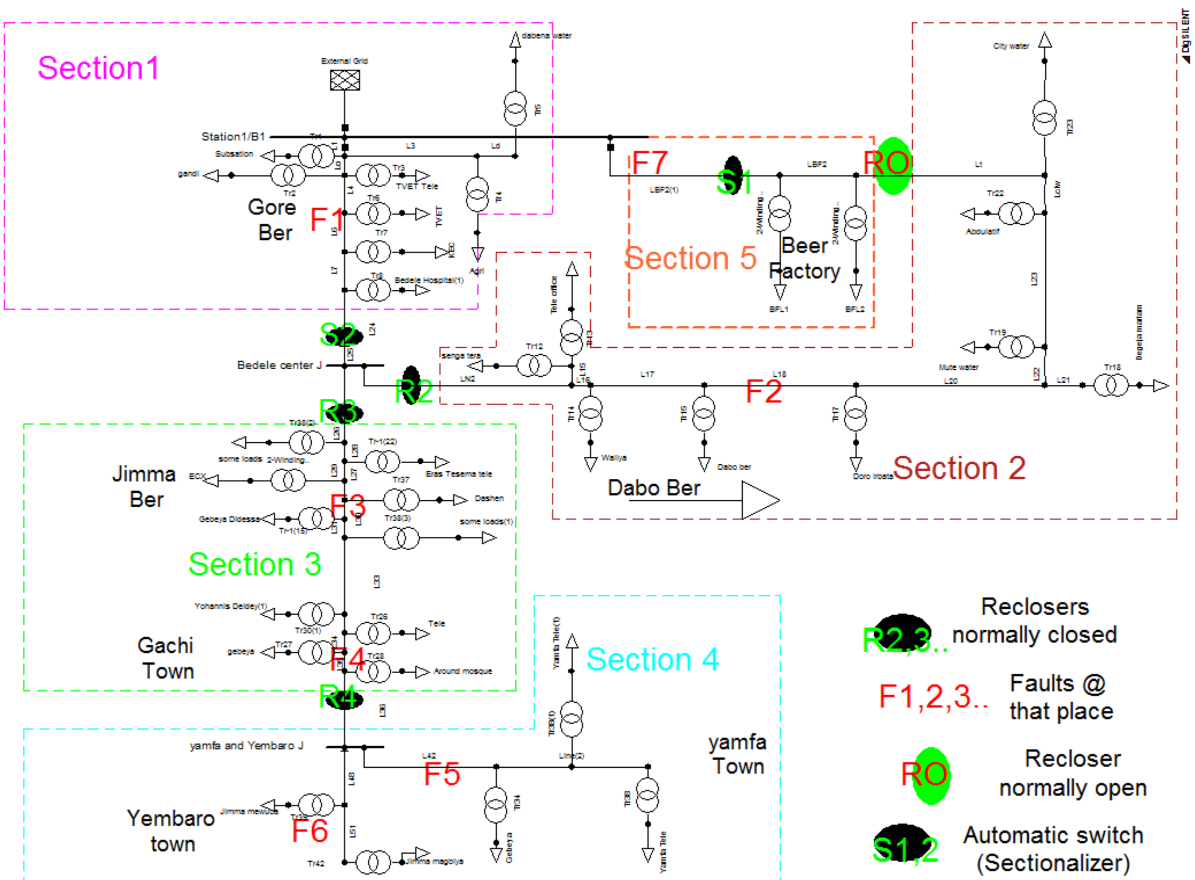

Figure 4.13: Auto Restoration of Bedele City and Bedele Brewery factory distribution system network model using four reclosers and twosectionalizers switches

Section1: when fault happen this section, circuit breaker in the substation will trip. S2 will isolate faulty section and Restoration power from Beer factory can supply other sections exceptsection1.

Thus, According to this model 56 int.hr/customer/yr and 48 f/customer/yr will occur in this section.

Section2: fault in this section is controlled by two reclosers. When fault occur in normal operation (supplying section from city line) recloser 2 will clear that faults. If fault happen in section 1 and this section is on maintenance time, section 2 and downstream load will get power via Beer factory line. So, in this mode of operation normally open recloser (Ro) will isolate the faults. According to this model 165 int.hr/customer/yr and 192f/customer/yr will occur in this section.

Section3: when fault happen in section this section recloser 3 will clear the fault. But, this fault affects section 3 loads and all the downstream loads. According to this model 148 int.hr/customer/yr and 177 f/customer/yr will occur in this section.

Section 4: when fault happen in section this section recloser 4 will clear the fault. But, this fault affects both yembaro and Yamfa towns. According to this model 489int.hr/customer/yr and473 f/customer/yr will occur in this section.

Section 5: when fault occur in this section, circuit breaker in the substation that control the Bedele beer factory line will trip and Switch1 (S1) will isolate faulty section. According to this model 0.38 int.hr/yr and 272 f/yr will occur in this section. Even though there is frequently interrupted power the same as existing power distribution system in this section, interruption duration is almost negligible since there is alternate source from Bedele city feeder.The overall reliability improvement model indices summarized as follows.

System Indexes

SAIFI	213.9884 f / customer.yr
SAIDI	192.5515 hr / customer.yr
CAIDI	0.900 hr / customer interruption
ASAI	0.9780 pu
ASUI	0.02198 pu
EENS	203.416 MW hr / yr
ECOST	0.00 $ / yr
AENS	3.9119 MW hr / customer.yr
IEAR	0.000 $ / kW hr

Figure 4.14: Simulation Summary Report of power distribution system using open tie recloser for Case B

Case C

In this model there are 6 sections.Protection devices are located at Gore ber, Dabo ber, jimma ber inter, jimma ber exit, Gachi outgoing and near Beer factory from Substation side and 1 normally open recloser to tie two feeders. Similar to case B, the role of Protection devices located at Gore ber and near Beer factory to Substation side is isolating faulty section. In order to reduce investment cost and protection coordination problem, these protection devices should be auto Sectionalizers (automatic switch) while others protection devices are reclosers.

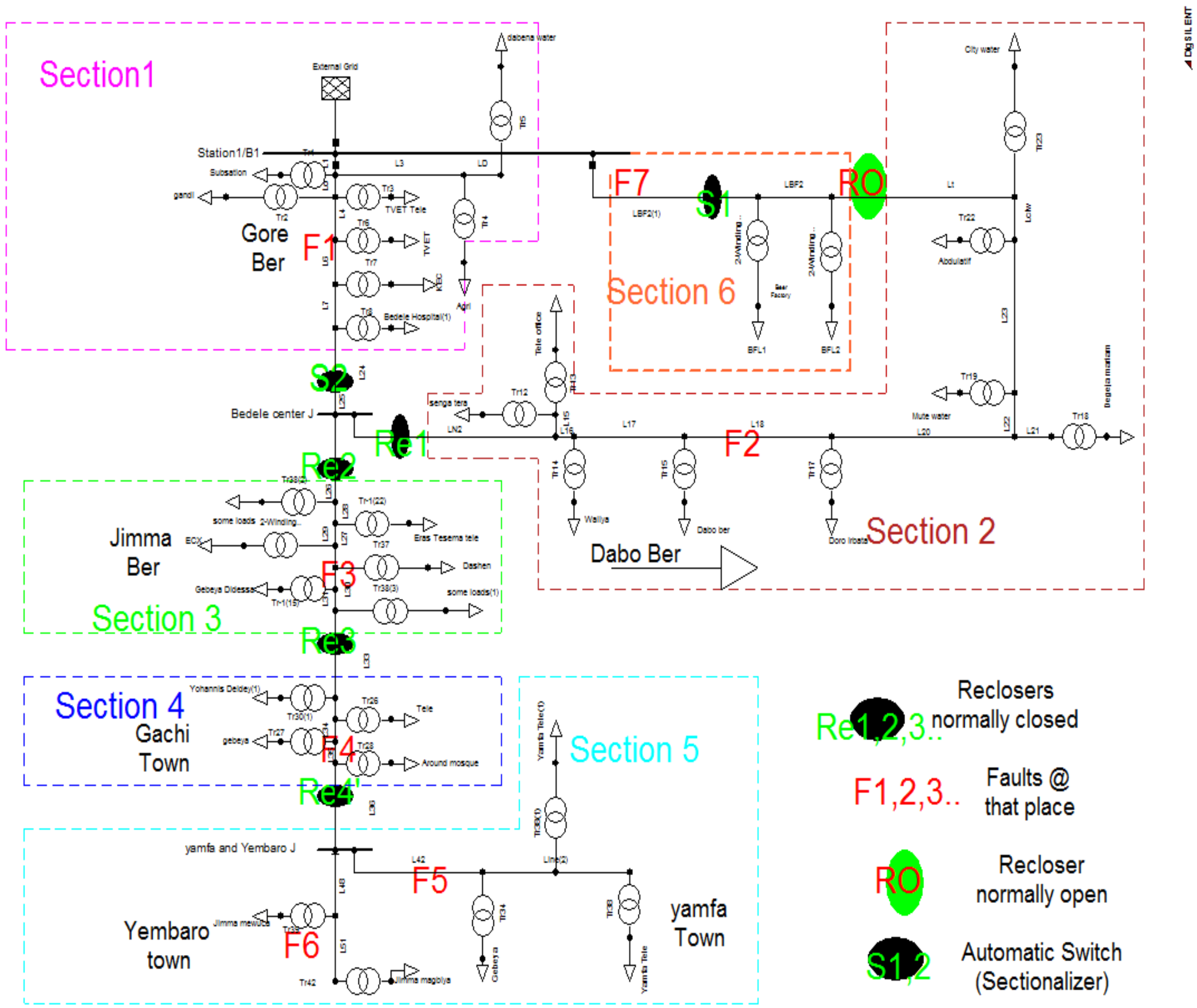

Figure 4.15: Auto Restoration of Bedele City and Bedele Brewery factory distribution system network model using five reclosers and two Sectionalizer switches

Section1: when fault happen this section, circuit breaker in the substation will trip. Restoration power from Beer factory can supply other section except section 1. Thus, According to this model 56 int.hr/customer/yr and 48 f/customer/yr will occur in this section.

Section2: fault in this section is controlled by two reclosers. When fault occur in normal operation (supplying section from city line) recloser 1 will clear that faults. If fault happen in section 1 and this section is on maintenance period, section 2 and downstream load will get power via Beer factory line. So, on this mode of operation normally open recloser (Ro) will isolate the faults. According to this model 165 int.hr/customer/yr and 192f/customer/yr will occur in this section.

Section3: when fault happen in section this section recloser 2 will clear the fault (F3). But, this fault affects section 3 loads and all the downstream loads. According to this model 19 int.hr/customer/yr and 65 f/customer/yr will occur in this section.

Section 4: when fault happen in section this section recloser 3 (Re3) will clear the fault. But, this fault affects both section 4 and downstream loads. According to this model 148.5 int.hr/customer/yr and 177 f/customer/yr will occur in this section.

Section 5: when faults (F5 or F6) happen in section4recloser 4 (Re4') will isolate the fault without affecting other sections. According to this model 489 int.hr/customer/yr and 473 f/customer/yr will occur in this section.

Section 6: when fault occur in this section, circuit breaker in the substation that control the Bedele beer factory line will trip and S1will isolate the faulty section. According to this model 0.38 int.hr/yr and 272 f/yr will occur in this section. Even though there is frequently interrupted power the same as existing power distribution system in this section, interruption duration is almost negligible due toauto restoration from Bedele city feeder.

System Indexes

SAIFI	196.6774 f / customer.yr
SAIDI	172.6426 hr / customer.yr
CAIDI	0.878 hr / customer interruption
ASAI	0.9803 pu
ASUI	0.01971 pu
EENS	188.146 MW hr / yr
ECOST	0.00 $ / yr
AENS	3.6182 MW hr / customer.yr
IEAR	0.000 $ / kW hr

Figure 4.16: Simulation Summary Report of power distribution system withopen tie recloser for Case C

<u>Case D</u>

In this model there are 6 sections. Protection devices are located at Gore ber, Dabo ber, jimma ber inter, Yembaro, Yamfa, near Beer factory from Substation side and 1 normally open recloser to tie with city feeder. Similar to case C, the role of Protection devices located at Gore ber and near Beer factory to Substation side is isolating faulty section. In order to reduce investment cost and protection coordination problem, these protection devices should be auto Sectionalizers (automatic switch) while others protection devices are reclosers.

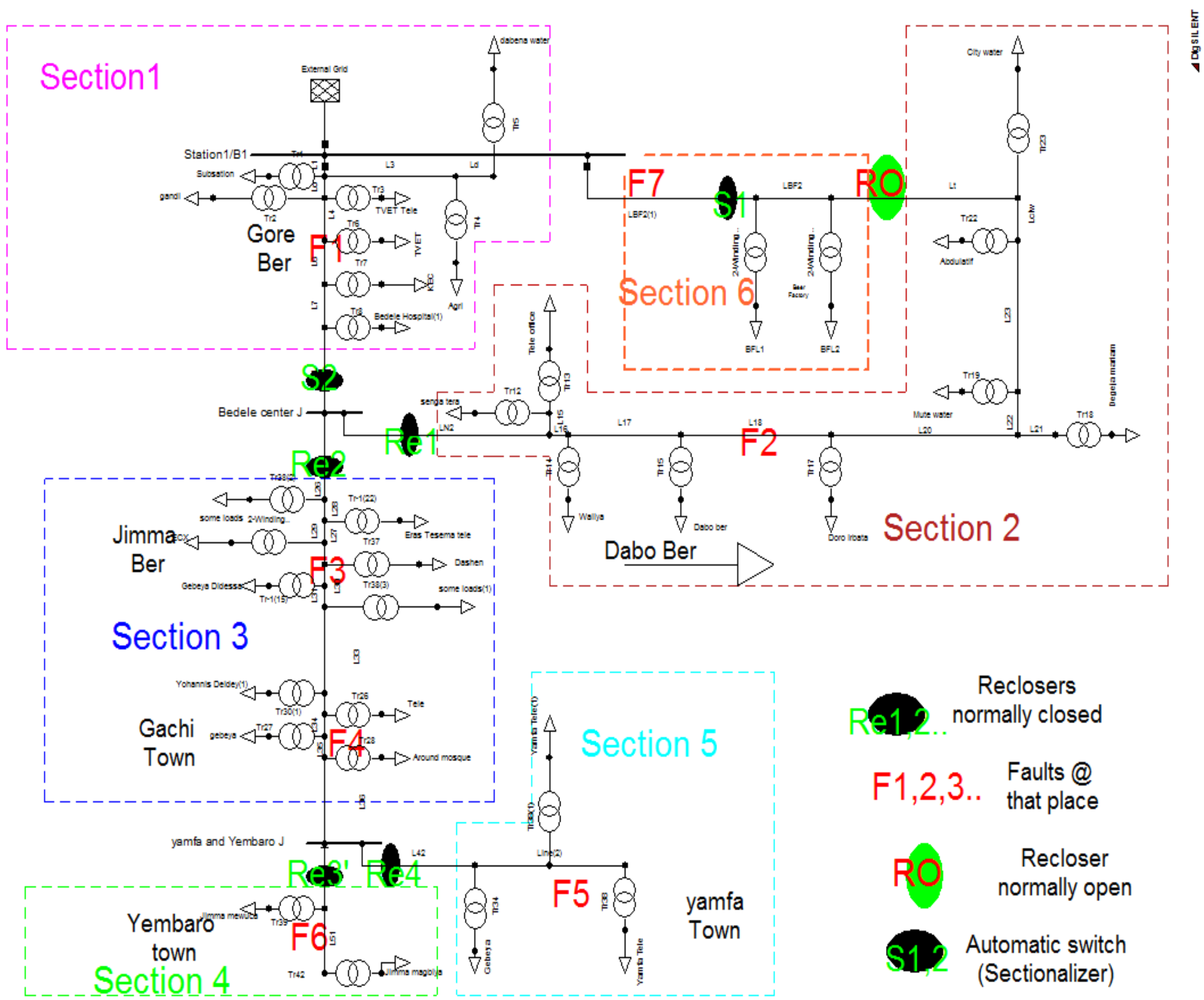

Figure4.17: Auto Restoration of Bedele City and Bedele Brewery factory distribution system network model using five reclosers and twoautomatic Sectionalizerswitches

Section1: when fault happen this section, circuit breaker in the substation will trip and S2 will isolate faulty section. Then restoration power form Beer factory can supply other section except section 1. Thus, According to this model 56 int.hr/customer/yr and 48 f/customer/yr will occur in this section.

Section2: fault in this section is controlled by two reclosers. When fault occur in normal operation (supplying section from city line) Recloser 1 will clear that faults. If fault happen in section 1 and this section is on maintenance time, section 2 and downstream load getting power via Beer factory line. So, at this time normally open recloser (Ro) will isolate the fault. . According to this model 165 int.hr/customer/yr and 192f/customer/yr will occur in this section.

Section3: when fault happen in section this section recloser 2 (Re2) will clear the fault. But, this fault affects section 3 loads and all the downstream loads. According to this model 182int.hr/customer/yr and 206 f/customer/yr will occur in this section. Here comparing to case C, bedele city of Jimma ber is going exposed to long interruption duration and high failure frequency.

Section 4: when fault happen in section this section recloser3’ (Re3’) will clear the fault. According to this model 284int.hr/customer/yr and 295 f/customer/yr will occur in this section. In this section this model has reliability improvement of almost two times comparing to case C.

Section 5: when fault happen in section this section recloser4’(Re4) will clear the fault. According to this model 284int.hr/customer/yr and 295 f/customer/yr will occur in this section. It has better reliability performance comparing to case C.

Section 6: similar to case C, when fault occur in this section circuit breaker in the substation that control the Bedele beer factory line will trip. According to this model 0.38 int.hr/yr and 272 f/yr will occur in this section. Even though there is frequently interrupted power the same as existing power distribution system in this section, interruption duration is almost negligible since there is alternate source from Bedele city feeder.

System Indexes

SAIFI	199.5109 f / customer.yr
SAIDI	175.9023 hr / customer.yr
CAIDI	0.882 hr / customer interruption
ASAI	0.9799 pu
ASUI	0.02008 pu
EENS	195.652 MW hr / yr
ECOST	0.00 $ / yr
AENS	3.7625 MW hr / customer.yr
IEAR	0.000 $ / kW hr

Figure 4.18: Simulation Summary Report of distribution system withopen tie recloser for case D

The above different models basic reliability indices summarized as follows.

Table 4.2:Basic system and load Reliability indices value for each auto restoration cases

Cases	Number of Section	Number of Reclosers	Number of automatic Sectionalizers	SAIFI	SAIDI	ENS (Mwh)
Existing	1	0	0	617	710	1115
A	4	3	1	326	322	272
B	5	4	2	214	193	203
C	6	5	2	197	173	188
D	6	5	2	200	176	196

As shown in above table reliability indices changed radically from existing case to case A model. Again there is significant improvement from case A to case B on all indices. But, from case B to case C there is less improvement comparing to improvement from case A to case B. without increasing number of recloser, but with different placement, Case C and D has almost same reliability improvement.This improvement can be compared using the following chart tool.

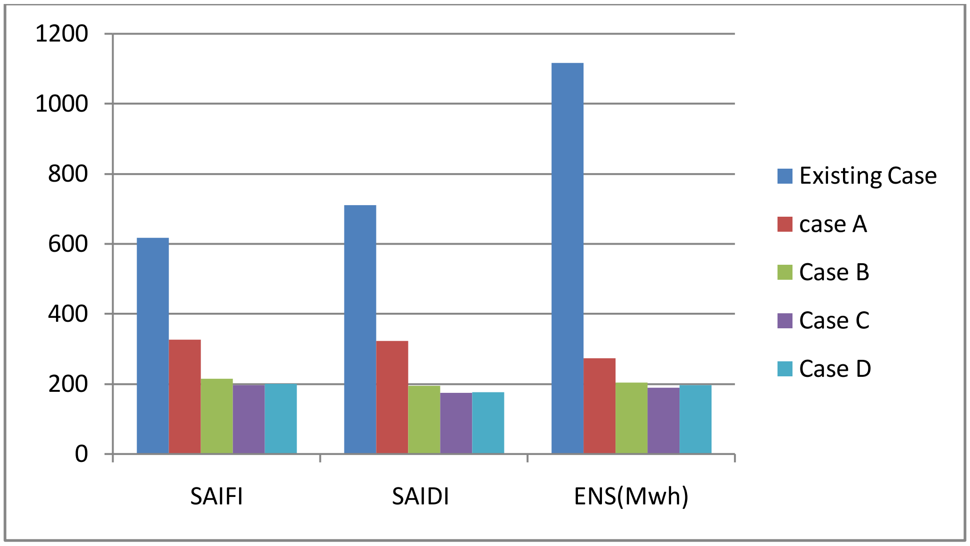

Figure 4.19: Chart that shows Reliability improvement in auto restoration cases

Even though, the investment cost of case C and case D are equal, there is slight reliability improvement difference between these models. In order to choose best scenario for implementing of this project, reliability performance and protection coordination issues must be considered.

As number of series recloser increase the protection coordination problem increase. From reference [37] for more than three reclosers CTI is insufficient for the protection devices in series. Since there are 4 four reclosers in series that must be coordinated in case C, case D is better. The protection coordination design usingTCC curve that shows protection coordination impracticability for case Cand correct protection coordination for case D will be verified using ETAP software in recloser size selection and protection coordination section.

4.2. Monetary Analysis of the power distribution system with protection devices

4.2.1. Calculating Payback Period for each case

It is obvious that further segmentation of long distribution system will improve reliability of distribution system. But, further segmentation lead to over investment for initial cost. So, it is necessary to compare the above different scenarios with respect to their investment cost. Using Ethiopian Electric Utility Tariff and international cost of recloser, pay period of each network model is calculated.

The investment cost can be calculated by using the cost of total smart reclosers used todesign the system. Average cost of one Smart Recloser is $9,000 (USD) (Based on the currency exchange on May 20, 2016, $1 = 21.85 Birr) [23]. Hence, the cost of one Smart Recloser is: 9,000*21.45 = 193,050 Birr. And the cost of one auto Sectionalizer is $3,000(USD) (based on the currency exchange on May 20,2016, (1$ =21.485)[28]. So, price of one Sectionalizer is 64,350 Birr.

The life time of the project is expected to be 25 years based on the smart reclosers and other accessories life time [1]. On the other hand, the payback period of the designed system for different cases is an important factor. Payback period is the length of time required to recover the cost of an investment. The payback period of a given investment or project is an important determinant of whether to undertake the position or project, as longer payback periods are typically not desirable for investment positions. The payback period in years can be calculated as:

$$\text{Payback period} = \frac{\text{Investement cost (birr)}}{\text{Annual saving (birr/year)}}$$

In each cases Energy not (ENS) sold index is used to calculate payback period. ENS values for cases 1 to 5 are 923,452.27, 295.36, 258.44 and 235.365 respectively.

<u>Case 1</u>: energy not sold in birr is for existing Bedele city feeder line:

Using 0.273 to 0.6943 Birr/kWh tariff, Cost of energy not sold for existing feeder line is

$$\text{Average Energy not sold in birr} = \frac{923{,}000\,\text{KWhx}\,[0.273 + 0.6943]\,\text{birr/kWh}}{2}$$

$$= 446408.95\text{birr/year}$$

Case 2: energy not sold in birr is for Bedele city feeder line segmented using two reclosers:

Using 0.273 to 0.6943 Birr/kWh tariff, Cost of energy not sold for existing feeder line is

$$\text{Average Energy not sold in birr} = \frac{323{,}000\,\text{KWhx}\,[0.273+0.6943]\text{birr}/\text{kWh}}{2}$$

= 156,218.95birr/year

Saved birr = Average energy not sold in birr for existing distribution system - average energy not sold using two recloser model

Saved birr = [446,408.95 – 156,218.95] birr/year

= 290,190 birr/year

$$\text{Payback period} = \frac{2\text{x}\ 196{,}650\,(\text{birr})}{290{,}190\,(\text{birr}/\text{year})} = 1.35\ \text{year}$$

Case 3: energy not sold in birr is for Bedele city feeder line segmented using three reclosers:

Using 0.273 to 0.6943 Birr/kWh tariff, Cost of energy not sold for existing feeder line is

$$\text{Average Energy not sold in birr} = \frac{255{,}000\,\text{KWhx}\,[0.273+0.6943]\text{birr}/\text{kWh}}{2}$$

= 123,330.75birr/year

Saved birr = Average energy not sold in birr for existing distribution system - average energy not sold using three reclosers model

Saved birr = [446,408.95 – 123,330.75] birr

= 323,307.95 birr/year

$$\text{Payback period} = \frac{\{3\text{x}196{,}650\}\text{birr}}{323{,}307.95\ (\text{birr}/\text{year})} = 1.82\ \text{year}$$

Case 4: energy not sold in birr is for Bedele city feeder line segmented using four reclosers:

Using 0.273 to 0.6943 Birr/kWh tariff, Cost of energy not sold for existing feeder line is

$$\text{Average Energy not sold in birr} = \frac{240\,\text{KWhx}\,[0.273+0.6943]\text{birr}/\text{kWh}}{2}$$

= 116,076birr/year

Saved birr = Average energy not sold in birr for existing distribution system - average energy not sold using four reclosers model

Saved birr= [446,408.95 – 116,076] birr

= 330332.95birr/year

$$\text{Payback period} = \frac{4\text{x}196{,}650\,(\text{birr})}{330{,}332.95\ (\text{birr}/\text{year})} = 2.38\ \text{year}$$

Case 5: energy not sold in birr is for Bedele city feeder segmented line using four reclosers:

Using 0.273 to 0.6943 Birr/kWh tariff, Cost of energy not sold for existing feeder line is

$$\text{Average Energy not sold in birr} = \frac{228\text{KWhx}\ [0.273+0.6943]\text{birr}/\text{kWh}}{2}$$

= 110,272.2birr/year

Saved birr = Average energy not sold in birr for existing distribution system - average energy not sold using five reclosers model

Saved birr = [446,408.95 – 110,272.2]birr/year

= 336,136.75birr/year

$$\text{Payback period} = \frac{5x196{,}650(birr)}{332{,}574.67\ (birr/year)} = 2.96\ \text{year}$$

Table4.3: Summary ofestimated payback period for the feeder segmentation cases

Case	Total Reclosers	Total cost of recloser(birr)	ENS (Mwah)	Saving (birr/year)	Payback period(year)
1	-	-	923	0	-
2	2	393,300	452.27	290,190	1.35
3	3	589,950	295.36	323,307.95	1.82
4	4	786,600	258.44	330332.95	2.38
5	5	983,250	235.365	336,136.75	2.96

From above table payback period varies from 1.35 to 2.96 year in these models. This shows that as reliability of the power distribution system improved, the investment cost will increase. Since the project is for 25 years, all payback period are tolerable. But, since case 2 and case 3 have less improved reliability indices these models will not be recommended for implementation. Therefore, case 4 and Case 5 should be compared to other scenarios and to each other. While comparing these models payback period and protection coordination problem must be considered.

Case 1 or existing two feeder energy cost: energy not sold in birr is for existing Bedele city feeder line and Bedele Brewery factory:

Using 0.273 to 0.6943 Birr/kWh tariff, Cost of energy not sold for existing feeder lines are

Average Energy not sold in birr from Bedele city line = $\frac{923{,}000\text{KWhx }[0.273 + 0.6943]\text{birr /kWh}}{2}$

= 446,408.95birr/year

Average Energy not sold in birr from Bedele Brewery line = 192,000kWhx0.6943birr/KWh

= 133,305.56birr/year

Total Energy not sold = 446,408.95 + 133,305.56birr/year

= 579,714.55birr/year

Case A: energy not sold in birr is for Bedele city feeder and Bedele brewery Factor auto restoration using three reclosers and 1 Sectionalizer:

Using 0.273 to 0.6943 Birr/kWh tariff, Cost of energy not sold for case Adistribution system model is:

Average Energy not sold in birr = $\frac{272{,}000\text{KWhx }[0.273 + 0.6943]\text{birr /kWh}}{2}$

=131,552.8birr/year

Saved birr = Average energy not sold in birr for existing distribution system - average energy not sold using threereclosers and 1 Sectionalizerauto restoration model

Saved birr = [579,714.55 – 131,552.8] birr/year

= 448,161.75birr/year

Payback period = $\frac{\{3x196{,}650 + 65{,}550\}birr}{448{,}161.75(birr\ /year\ )}$ = 1.46 year

Similarly by calculating for other cases:

Case B: Energy not sold in birr is for Bedele city feeder and Bedele brewery Factory auto restoration using four reclosers and 2 Sectionalizers:

Using 0.273 to 0.6943 Birr/kWh tariff, Cost of energy not sold for existing feeder line is

Average Energy not sold in birr = $\frac{203{,}000\text{KWhx }[0.273 + 0.6943]\text{birr /kWh}}{2}$

= 98,180.95birr/year

Saved birr = Average energy not sold in birr for existing distribution system - average energy not sold using four reclosers auto restoration model

Saved birr = [579,714.55 – 98,180.95] birr/year

= 481,533.6birr/year

Payback period = $\frac{\{4x196,650+2x65,550\}birr}{481,533.6(birr/year)}$ = 1.91 year

Case C:

Energy not sold in birr is for Bedele city feeder and Bedele brewery Factory auto restoration using five reclosers and two Sectionalizers:

Using 0.273 to 0.6943 Birr/kWh tariff, Cost of energy not sold for existing feeder line is

Average Energy not sold in birr = $\frac{188,000\text{KWhx }[0.273+0.6943]\text{birr/kWh}}{2}$

= 90,926.2birr/year

Saved birr = Average energy not sold in birr for existing distribution system - average energy not sold using seven reclosers auto restoration model

Saved birr = [579,714.55 – 90,926.2] birr/year

= 488,788.35birr/year

Payback period = $\frac{\{5x196,650+2x65,550\}birr}{488,788.35(birr/year)}$ = 2.28 year

Case D: Energy not sold in birr is for Bedele city feeder and Bedele brewery Factory auto restoration using five reclosers and two Sectionalizers:

Using 0.273 to 0.6943 Birr/kWh tariff, Cost of energy not sold for existing feeder line is

Average Energy not sold in birr = $\frac{196,000\text{KWhx }[0.273+0.6943]\text{birr/kWh}}{2}$

= 94,795.4birr/year

Saved birr = Average energy not sold in birr for existing distribution system - average energy not sold using seven reclosers auto restoration model

Saved birr = [579,714.55 – 94,795.4] birr/year

= 484,919.15birr/year

Payback period = $\frac{\{5x196,650+2x65,550\}birr}{484,919.15(birr/year)}$ = 2.3 year

Table 4.4:Summary of estimatedpayback periodfor auto restoration cases

Case	Number of recloser	Number of Sectionalizer	Total cost of protection device (birr)	ENS (Mwah)	Saving (birr/year)	Payback period(year)
1	-	-	-	1115	0	-
A	3	1	655,500	468.3	448,161.75	1.46
B	4	2	917,700	282	481,533.6	1.91
C	5	2	1,114,350	236.8	488,788.35	2.28
D	5	2	1,114,350	242	484,919.15	2.3

From above table payback period varies from 1.4 to 2.3 year in these models. Since there is no long time payback period all payback period are tolerable. Since case A and case B have less improved reliability indices these models will not be recommended for implementation. Therefore, case C and Case D should be compared to case 4 and case 5. While comparing these models payback period, Reliability indices and protection coordination problem must be considered.

Comparing case C with case 4 and Case 5:
Case C has better SAIDI and ENS indices comparing to case 4 and Case 5. In case C Model the customer would get power for 50Hr/year and 27hr/year duration better than case 4 and Case 5 respectively. It has also better payback period. This model, each customer would face additional 6failure/year and 23failure/year comparing to Case 4 and case 5 respectively. Case 4 has nearly same SAIFI value comparing case C. In Practical case customer prefer getting continuous power for 27Hr/year rather than facing 23failure per year. So, on average Case C is better model comparing to above two cases.

Comparing Case D with Case 4 and case 5:
Case C has better SAIDI and ENS indices comparing to case 4 and Case 5.In case D Model the customer would get power for 47Hr/year and 24hr/year duration better than case 4 and Case 5 respectively. It has also better payback period.On average Case D is better model comparing to above two cases.

Generally, Case C and case D are better scenarios. So, it is better to compare these cases. Case C is better than case D by 3failure/cust.year, 3 Hr.int/cust.year and 8MWh/year. While comparing these cases difference in terms their reliability indices, they are nearly same. So, for practical implementation, it is better to consider other constraint like protection coordination problem. It is obvious that as number of series recloser increases, protection coordination problem arises. Thus, protection coordination for both of them should be done using ETAP software.

4.2.2. Monetary analysis of Bedele Brewery Factory using auto restoration

Generally, all scenarios are possible to be implemented since they have certain contribution to reliability improvement with different investment cost. All payback costs are good comparing to the age of the project. Above all, since there is high interruption rate and duration Auto power restoration distribution model should be implemented. In order to shows advantage of loop power restoration model, Bedele Brewery factory monetary analysis is done for auto restoration case. These cases have equal contribution to reliability improvement for Bedele brewery factory load.

Based on the production capacity of the factory, effort has been exerted to estimate the production loss due to the interruption of the power. Therefore, the following analysis is done for the average interruption hours based on the data obtained from the autorestoration model simulation result. Simulation result shows that there is only 0.38int.hr/yr.

In order to reduce revenue loss due to power interruption diesel generator is used. To estimate the cost expense due to fuel consumption: Existing Diesel generator that supply Factory has power factor of 0.8, consume 200Lt fuel per Hour. So,

Fuel expense = Consumption liter per hour *cost of fuel per liter* Average interruption duration

= 200Lt/hour*16.5birr/Lt*0.38hour

= 1,254birr/year

The Factory is also using diesel generator for Dabena water (water pumping for Factory) with rating 175KW. Fuel consumption of this generator is 400L/24Hr (16.67L/Hr). Similarly, from ETAP simulation result of auto restoration new system, section 1 interruption duration is 56in.hr/yr. therefore,

Fuel expense = Consumption liter per hour *cost of fuel per liter* Average interruption duration

= 16.67Lt/hour*16.50birr/Lt*56hour

= 15,403.08birr/year

Total cost expense due to fuel consumption = 1,254birr/year + 15,403,08birr/year

= 16,657.08birr/year

From section 3.3 Total cost expense due to fuel consumption for existing distribution system is

= 1,048,970.03Birr/Year

Saved fuel cost = Fuel cost due existing distribution system- fuel expense of New Distribution model

=1,048,970.03Birr/Year –16,657.08Birr/Year

= 1,032,312.95birr/year

If this project is implemented, the factory will save net of1,032,312.95birr/yearfrom fuel cost due to distribution line interruptions.

Since, Factory is using manual Generator starting it takes to start product from 5 to 10 minutes. For 272 interruptions, on average 7x272 minutes or 31.7Hr interruption duration will be unproductive period for factory due distribution system power interruption. As mentioned in section 3.3 the rated capacity of the factory is 36,000 bottles per hour. The Factory sell beer product minimum by 7.25 birr/bottle. If the factory were not using backup generator, the revenue loss would be high. Thus, using average rate production of 35,000bottles/hh, in 31.7 hour the Factory can produce:

Cost expense in unproductive period = 31.7Hrx35,000Bottles/Hrx7.25birr/bottle

= 8,052,333 birr/year

But, for new model of power distribution system:

Average production loss of Factory = 35,000bottles/hr*7.25birr/bottle*0.38 int.Hr/year

=, which is almost negligible time

Net revenue from new model = 8,052,333 birr/year - 96,425Birr/yr

= 7,955,908 Birr/year

The above customer side cost analysis indicates that customer will face high revenue loss from their product and due to fuel expense. Beer Factory is taken as an example, each customer according to their energy consumption and their product type they will experience different levelof revenue loss. So, implementing this project to improve reliability of existing power distribution system is useful both for customer and utility.

4.3. Reclosers Application Criteria

The basic reclosers' application criteria are discusses under this section.

1. System voltage: The recloser must have a voltage rating equal to or greater than the system voltage.
2. Maximum fault current available at the recloser location: The recloser interrupting rating must be equal to or greater than the maximum available fault current at its location.
3. Maximum load current: The recloser continuous current rating must be equal to or greater than the anticipated circuit load. For series-coil-type reclosers, the coil size can be selected to match the present load current and the anticipated future load current. Minimum-trip current is nominally twice the coil continuous-current rating. For electronically controlled reclosers, minimum-trip current must be greater than any anticipated peak load. Generally, a trip-current value of at least twice the expected load current is used.
4. Minimum-fault current within the zone to be protected: The recloser should sense and interrupt the minimum fault current that might occur at the end of the line section.
5. Coordination with other devices: Recloser timing and sequences are selected to coordinate with the source-side devices. After the size and sequence of the required recloser has been determined, the protective equipment down the line is selected to coordinate with it.

The maximum load current that may go through a protective device in the closed-loop distribution systems should be the sum of all its downstream loads without regarding to the load sharing by the source in the other sides. This maximum load current is used to determine the lower limit of the pickup current of the relevant protective devices. I pick up ≥ K maxload x I max load. Here K max load is the safety factor, and generally it is no less than 1.5 for phase fault and around 0.3 for phase ground fault.To assure that the protective devices will see all of the faults, the pickup current should be less than the possible minimum fault current that may happen in the protection zone. So one of the upper limits determined by the minimum fault current is:

I pick up ≤ Kminf x Iminf

Here Kminf is the safety factor, and generally it is 1.0 for phase fault and around 0.5 for phase-ground fault. Here exact maximum load of each section is unknown, so upper limit is used [37].

4.3.1.Recloser size selection

1. System voltage: The recloser must have a voltage rating equal to or greater than the system voltage. In Bedele city and Bedele brewery factory power distribution system voltage level is 15KV. So, 15KV recloser is chosen in this model.
2. Maximum fault current available at the recloser location: The recloser interrupting rating must be equal to or greater than the maximum available fault current at its location. From ETAP simulation, maximum fault current is evaluated at different possible location of recloser.

Table 4.5: Maximum short circuit current summary report for case C and Case D model

Bus		3-Phase Fault			Line-to-Ground Fault			Line-to-Line Fault			*Line-to-Line-to-Ground		
ID	KV	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.
Bus for Re2 sizing	15.00	4.432	-2.133	4.918	2.498	-2.597	3.603	1.847	3.838	4.259	1.116	4.969	5.093
Bus for Re3' sizing	15.00	0.358	-0.133	0.382	0.183	-0.191	0.264	0.115	0.310	0.331	0.066	0.390	0.395
Bus for Re4 sizing	15.00	0.358	-0.133	0.382	0.183	-0.191	0.264	0.115	0.310	0.331	0.066	0.390	0.395
Bus for Re4' sizing	15.00	0.424	-0.158	0.452	0.217	-0.226	0.313	0.137	0.367	0.392	0.079	0.462	0.468
Bus for Re3 sizing	15.00	2.015	-0.834	2.181	1.069	-1.111	1.542	0.722	1.745	1.889	0.426	2.218	2.259
Bus for Ro sizing	15.00	6.854	-2.498	7.295	3.483	-3.627	5.028	2.163	5.935	6.317	1.236	7.452	7.554
Bus for Re1 sizing	15.00	4.432	-2.133	4.918	2.498	-2.597	3.603	1.847	3.838	4.259	1.116	4.969	5.093

From above simulation result maximum fault current is line-line -to- ground fault current which is 7.554KA. Therefore, recloser with size greater than 7.55KA must be selected. By taking into consideration high demand of electricity, 800Amaximum continuous current rating and 12KA interrupting rating recloser must selected for R0, Re1, Re2 and Re3 since they would face maximum fault current of 7.55KA, 5.093KA, 5.093KA and 2.259KA respectively. Similarly for other reclosers size selection, Line –Line –to-ground has maximum fault current of 395A and 468A for Re3' and Re4' respectively. And maximum L-L-G fault current of 395A for Re4. So, again taking into consideration of power demand increment, 400A maximum continuous current rating and 12KA interrupting rating Recloser is selected for Re3', Re4 and Re4'.

3. Maximum load current: The recloser continuous current rating must be equal to or greater than the anticipated circuit load. Generally, a trip-current value of at least twice the expected load current is used. In this case study exact loading of each section is unknown, so, upper limit is basic to determine the protection coordination of the system.

a. Normal operation condition: In normal operation load flow analysis shows that there is 25A, 11A, 6.4A, 3.8A, 1.6A and 2.1A for Re1, Re2, Re3, Re4', Re3' and Re4 respectively.
b. If fault happen on Gore ber section: at this condition Bedele city line is getting power from Bedele brewery factory, normally open tie recloser will have 35.2A.While other remain at their load current. Here Bedele Brewery Factory will face normal current of 59A.
c. If fault happened on Beer factory line: In this condition recloser1 (Re1) will have high load current comparing to normal case current which is 48A. Bedele city feeder will face 58A load current.

4. Minimum-fault current within the zone to be protected: The recloser should sense and interrupt the minimum fault current that might occur at the end of the line section.

Table 4.6: Fault summary report for minimum fault current determination

Bus		3-Phase Fault			Line-to-Ground Fault			Line-to-Line Fault			*Line-to-Line-to-Ground		
ID	KV	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.	Real	Imag.	Mag.
Min If dabo ber Re1 / R0	15.00	0.372	-0.174	0.410	0.203	-0.212	0.293	0.150	0.322	0.355	0.092	0.413	0.423
Min If jimma ber Re2	15.00	2.015	-0.834	2.181	1.069	-1.111	1.542	0.722	1.745	1.889	0.426	2.218	2.259
Min If yamfa Re4 / Re4'	15.00	0.174	-0.064	0.186	0.089	-0.092	0.128	0.055	0.151	0.161	0.032	0.190	0.192
Min If yembaro exit Re3'	15.00	0.234	-0.086	0.250	0.120	-0.124	0.173	0.075	0.203	0.216	0.043	0.255	0.259
Min If for City Relay	15.00	4.481	-2.157	4.973	2.526	-2.626	3.644	1.868	3.881	4.307	1.129	5.025	5.150
Min If for Beer F Relay	15.00	7.219	-2.632	7.683	3.668	-3.820	5.296	2.279	6.251	6.654	1.302	7.849	7.956
Min If Gachi exit Re2	15.00	0.358	-0.133	0.382	0.183	-0.191	0.264	0.115	0.310	0.331	0.066	0.390	0.395
Min If Gachi exit Re3	15.00	0.424	-0.158	0.452	0.217	-0.226	0.313	0.137	0.367	0.392	0.079	0.462	0.468

Recloser1 (Re1): from this fault simulation result there is phase to phase fault and ground faults. So, minimum fault current should be according to their fault type. As shown above minimum fault current for phase fault is 355A and 293A for ground fault. Similarly for other reclosers minimum fault are as follows:

Recloser 2(Re2): minimum phase fault current is 285A and 228A for ground fault for Case D. minimum phase fault current is 1889A and 1542A for ground fault for case C.

Recloser3 (Re3): minimum fault current for phase fault is 392A and 313A for ground fault.

Recloser3' (Re3'): For this recloser minimum fault current is determined from Yembaro exit. Thus, minimum fault current for phase fault is 216A and 173A for ground fault.

Recloser4 and Recloser 4' (Re4 &Re4'): For these reclosers minimum fault current is determined from Yamfa exit. Thus, minimum fault current for phase fault is 161A and 128A for ground fault.

Bedele city Circuit breaker: Here the circuit breaker will exposed to minimum fault current of 4.307KA for phase fault and 3.644KA for ground fault as from simulation result.
Bedele Brewery Factory circuit breaker: This circuit breaker will face minimum phase fault current of 6.654KA and 5.296KA for ground fault.

5. Coordination with other devices: coordination is Proper trip sequencing of protective devices to isolate the fault and minimizing outage. After the size and sequence of the required recloser has been determined, the protective equipment down the line is selected to coordinate with it.

4.3.2. Protection Coordination

Case C Model protection coordination

Protection coordination is done for case C model using ETAP star. Star is a fully integrated system protective device coordination and selectivity module within ETAP. Star enables power engineers to easily and efficiently perform protective device coordination studies. Electronically controlled units are simply coordinated with manufacturer's time-current curves. Thus,for phase and ground fault protection, proper coordination is done using ETAP. Here, outgoing lines controlling relay setting is used as reference. These base values are 1 sec for phase trip and 0.75sec for earth trip for Bedele city setting.While both phase and earth fault tripping time for Bedele Brewery factory is 1 sec. Using minimum 0.3 sec for recloser-recloser TCC curve separation and minimum of 0.25 sec for relay-recloser curve separation protection coordination is done for these new models.

For auto Sectionalizer that used to isolate faulted section no need of protection coordination, it can simply set to single shoot. That means when Bedele city or Bedele brewery factory tripped, it will isolate faulty section automatically in order to facilitate downstream load to be supplied. From either of lines after closing of open tie recloser.

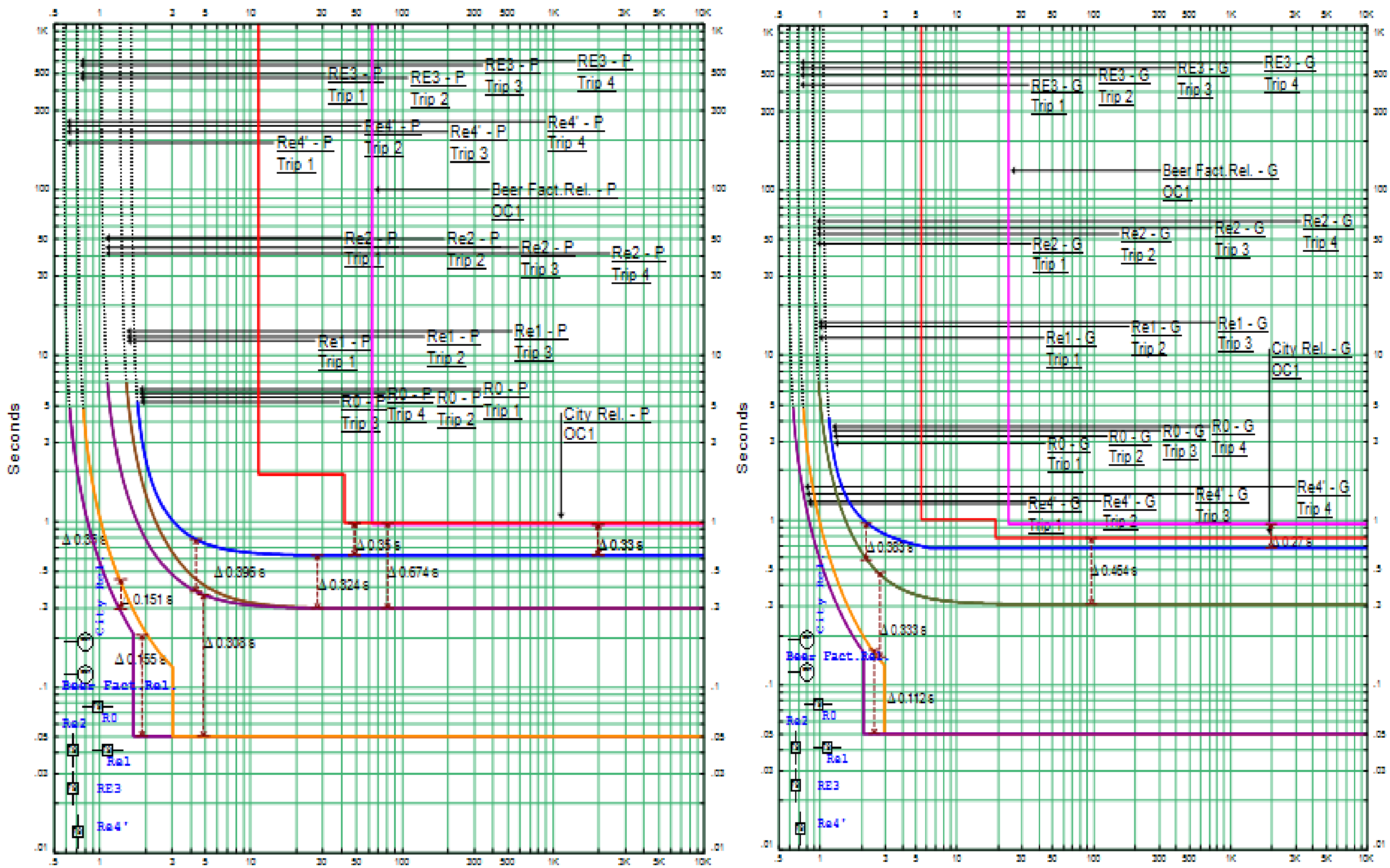

Figure 4.20: TCC curve that shows protection coordination impracticability for case C using ETAP software

In this model available protection devices are City Relay (City Rel), Recloser 1(Re1), Recloser 2(Re2), Recloser3 (Re3), Recloser4'(Re4'), Recloser0(R0) and Beer factory relay (Beer fact. Rel). Here designing proper protection coordination is difficult. By considering the above TCC, coordination between Recloser3 (Re3) and Recloser4' (Re4') don't have enough margin to trip which is less than 0.3sec

Case D Model protection coordination

In this model available protection devices are City Relay (City Rel), Recloser 1(Re1), Recloser 2(Re2), Recloser3 (Re3'), Recloser4(Re4), Recloser0(R0) and Beer factory relay (Beer fact.Rel). For this model proper protection coordination can be done properly as following. Here there are enough time margins between series protection device. With minimum of 0.3sec TCC curve separation for electronic recloser and minimum of 0.25 sec for Relay to recloser TCC curve separation.

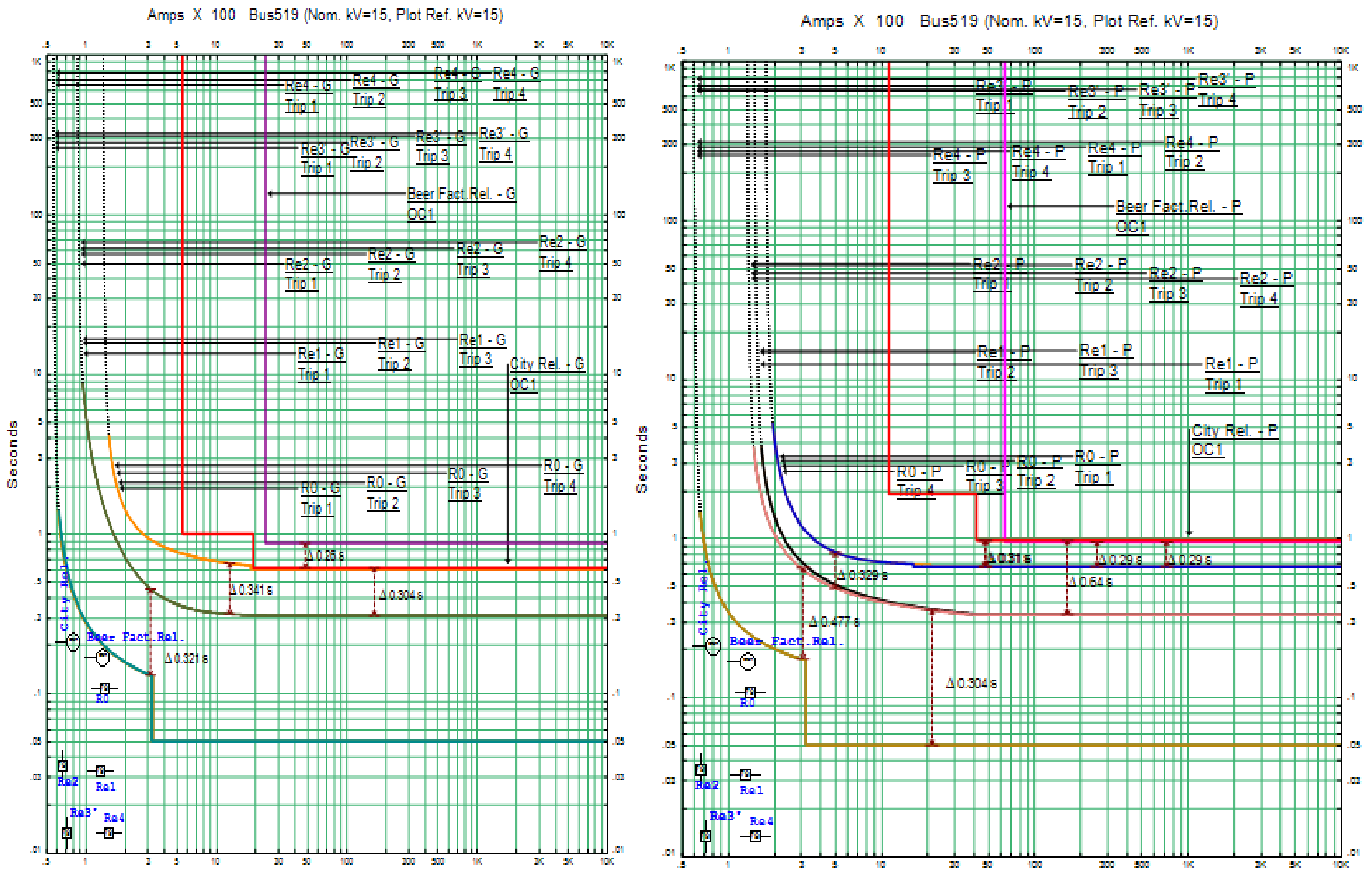

Figure 4.21: TCC curve that shows correct protection coordination of case D

Generally, while comparing these two cases (C and D), Case D is proper for practical implementation due to proper protection coordination. As above TCC curve shows Re2 is back up protection for the faults that going to happen downstream to Re3' and Re4. To make more reliable Bedele Brewery factory Feeder, Bedele Beer factor relay don't used as back protection for faults downstream to Ro and Re2.

CHAPTER FIVE

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORKS

Based on the results obtained from the reliability analysis of Bedele city power distribution system, this section discusses the major conclusions, the most important recommendations and the suggested main areas of future work.

5.1. Conclusion

Based on the results of this research work, the reliability of the Bedele city power distribution system does not meet the requirements set by the regulatory body that is, Ethiopian Electric Agency (EEA). The average frequency of interruptions of Bedele city present feeder is 617 interruptions per customer per year and the average duration of interruptions is 710 hours per customer per year. And also, the reliability of Bedele city power distribution system is not good enough as compared to the international reliability indices of best experienced countries such as Germany.

Similarly, Bedele Brewery factory Distribution system Reliability is far from requirement set by regulatory body. The average frequency of interruption of this line at present is 272 interruptions per customer per year and average duration of interruption is 320 hours per customer per year.

In this thesis different Distribution model proposed and analyzed. As above simulation result shows all Distribution models have different Reliability improvement contributions with 1.33 to 2.87 payback investment cost. All scenarios are tolerable in terms of investment cost. But, to improve reliability indices more and for proper protection coordination, case D is highly recommended. By implementing this model the overall reliability of power distribution is improved by 67.6%, 75.2% and 82.4% for SAIFI, SAIDI and ENS respectively. Similarly for Bedele Brewery Factory overall reliability is improved by 99% for both SAIDI and ENS.

Monetary analysis of Beer factory shows that there is huge revenue loss due to Distribution system power outage. If new Model case D is implemented, from the factory it is possible to save 1,032,312.95birr/yearfrom fuel expense. In addition, auto restoration reduceunproductiveperiod of the factory. Thus, total 7,955,908 Birr/yearwill be saved from unproductive time (down time).

5.2. Recommendation

The Ethiopian Electric Utility (EEU) should work to improve the reliability of the power distribution system at Bedele city. The existing grid should be modernized to meet the reliability standards. Based on this thesis result, it is possible to assured that using protection device along the feeder line can improve the reliability of the existing power distribution system. But, it is not enough to meet requirement of the Ethiopian Electric Agency (EEA). To meet this requirement it is necessary to reduce causes of faults in this city. This can be done by tree trimming, scheduled Inspection of Poles and Conductors clearance,scheduled preventive maintenance to poles and conductors, inspection of distribution transformers and conduct regular changing of oil.

5.3. Future Work

The following tasks are suggested as most important areas of study in the future.

1. In-depth study of the deployment of protection Devices used for distribution system reliability improvement.
2. Annual Customers outage cost due to electric power interruptions in Bedele city.
3. Distribution system reliability improvement using Distribution generations.
4. Smart grid Development for Bedele power distribution system.

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